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Master of Science Thesis

A DIDACTIC TEST BENCH FOR A CAR'S ENGINE

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Abstract

The test bench for a car's engine is a tool for measuring and testing the operating behaviours and mechanical characteristics of the engine. It takes the engine and ECU out stand a car, therefore, people can test the engine without a real car. This thesis introduces an engine test bench which is used in the didactic process for high school students. With this didactic test bench, teacher can teach the students with a real engine in the classroom, instead of just using textbooks or pictures. In this way, the students could learn and understand the working principle and structures of an engine more easily and clearly. The entire project consists of three parts: the first part is to design and build a simulation test bench with an Arduino board and some electronic components. The second part is to build a real test bench which include the mechanical part and the electrical part. The third part is analyzing the data which collected from the engine when it is working. An old Fiat punto 1.2 8V engine is used to test, the results show the good and defective working condition of the engine. Now it has been used for teaching in class at Filos. This research project collaborated by the institution Filos and Politecnico di Torino. And since this project is complicated, three students devoted working together to finish it.

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Nomenclature

Chapter 2:

W	work	J
F	force	N
L	Distance (in this thesis is the lengthe of the cylinder)	M
P	Pressure	Pa
S	The pistion area	m^3

Chapter 3:

P0	Normalized pressure	Pa
m_a	Mass of the air	Kg
$m_{a,th}$	Theoretical amount of air	Kg
ρ_0	Density of the air	kg/m^3
V_d	Cylinder displacement volume	m^3
λ_a	Relative air supply	
m_f	Mass of the fuel	Kg
$m_{f,th}$	Theoretical amount of fuel	Kg
λ_f	Relative fuel supply	
L_{st}	Stoichiometric ratio	
λ	Air-fuel ratio	

Chapter1 Introduction

The Test bench for a car's engine is a tool for measuring and testing the operating behaviour and mechanical characteristic of an engine. It takes the engine and ECU outstand a car, people can measure and test the operating behaviour and the mechanical characteristics of the engine without a real car.

The didactic test bench for a car's engine is an engine test bench which used in the teaching field. As a teaching tool in the engine teaching process, it can provide a lot of help for teachers and students. For example, teachers can teach the students how to mount the mechanical part of an engine and how to connect the electronical part of an engine. Through the data collected from the engine, the engine test bench also can verify the working condition of the engine and detect the fault of the components of the engine. In addition, the students and teachers also can do many kinds of testing on the engine test bench.

In this project, a Fiat Punto 1.2 8V engine is chosen as the test object. To make the students understand the engine working principle easily, a simple simulation of the engine is built with an Arduino board at first. The simulated test bench simulates the basic working principles of the engine. Then a real didactic engine test bench is built.

At the end of the project, a series of tests were done on the test bench. Then some data collected from the test bench can be processed and analyzed, so that we can understand the working condition of the engine and see the engine parameters relation from the results.

Since this project need strong basic knowledge about the engine, it is a complex project for three students whose major is mechatronics. There are a lot of preparation to be done at the beginning. Thanks to the help of the supervisor in the Filos and the two tutors from Politecnico di Torino, the didactic test bench for the car's engine was finally built successfully and can be used in the didactic process.

As mentioned before, the project is complex and has a large workload, so it is better to assign the work to the three students and the three students can work parallelly. In this way, the working time can be reduced.

The projects that the three students are responsible for are:

- The first student mainly works on the hardware. This is to say that the student is responsible for the electric part and the mechanic part of the engine. Because the engine should be mounted together before the test and the electric circuit could control the engine running.

- The second student mainly works on the data analysis part, including the data collection, data processing and the data analysis. Because after running the engine, lots of data will be collected by the EOBD. Then the testers can get the working condition of the test bench from the data.

- The last teammate should do a simulation of the engine with the Arduino in order to make the students understand the engine's working principle easily.

This thesis introduces all the works of the three students. But since I am the student who is responsible for the hardware, the engine preparation, the electric part design and the connection will be mainly introduced.

1.1 Individual contribution

After studying the literature of the engine, the structure of the engine and the working principle of each components was clearly. The works that I am mainly response is the hardware and electric circuit building of the test bench, which are:

- Cleaning the engine, testing the sensors and actuators and the engine installation.

- Connecting protect circuit that connected to the ECU connector part A and design the indicating circuit of the engine test bench.

- Making the EOBD connector and collecting the data from running engine.

1.2 Structure of the thesis

Chapter 1: Introduction of the thesis

Chapter 2: Literature review on the engine

A literature review on the engine is presented in this chapter. The presentation includes the types of the engine, the working principle of the 4 strokes spark inertial combustion engine and the engine start process with the start motor.

Chapter 3: Engine test stand design

Before building the engine test bench, an important issue is where to place the engine. So, the engine test stand's building is the first step to begin the work. There are two basic points should be considered about the engine test bench design: the material and the shape. The test stand keeps being improved with the project going.

Chapter 4: The engine preparation

Since the limit of the funds, an old Fiat Punto 1.2 8V engine is used in the project. So, before using it, the cleaning of the engine is necessary. In this chapter, introduces the engine cleaning and the tests of the sensors and actuators.

Chapter 5: The electric part of the test bench

From the chapter 4, the engine was prepared for the project, but the engine can not run only with the mechanic part. In this chapter, the circuit of the ECU has been connected. Furthermore, the indicating circuit of the engine also has been designed and connected.

Chapter 6: The preparation for running the engine

After the chapter 3, the chapter 4 and the chapter 5, the engine test bench is almost finished. But for running the engine, the last check must be prepared. In this chapter, introduces the last checking before the engine runs.

Chapter 7: The data acquisition strategy

In the chapter 7, introduces two diagnostics which can collect the data from the running engine. Bosch diagnostics and the Multiecuscan diagnostics. But after the comparison, the Multiecuscan is used in this project.

Chapter 8: Running the engine

It is for sure that the engine can not to run immediately after building. In this chapter, descripted the 4 attempts to run the engine. After solving the problems step by step, the engine runs successfully at the last.

Chapter 9: Data processing

After the chapter 8, the engine runs successfully, and the Multiecuscan get lots of data from the running engine. In this chapter, presents the types of the Data that Multiecuscan collect. And introduces the data processing in this project.

Chapter 10: The data analysis

In this chapter, analyzed some data after the data processing.

Chapter 11: Conclusion

A conclusion of this thesis and introduces some future works that can improve the didactic engine test bench.

Chapter2 Literature review on the engine

Before building an engine test bench, the basic knowledge of an engine must be prepared at first. So that the next work can be carried out smoothly. In this chapter, the basic knowledge of the engine is going to be introduced through a theoretical way.

An engine is a machine which converts one form of energy into mechanical energy. While, the energies can be, the heat, the electric, the compressed air .

The engine can classification according to two criteria:

• The form of energy it accepts

• The type of motion it outputs

Type of the engine:

• Heat engine

• Combustion engine

• Internal combustion engine

• External combustion engine

• Air-breathing combustion engine

Since the funds is limited in the project, it is a good choice to use an old engine. The old engine Fiat 1.2 8V is used in the thesis. This engine is an inertial combustion engine. It is an engine which converts the chemical energy that obtained in the fuel released by oxidation into the mechanical energy.

The inertial combustion engine classification criteria are based on the different parameters that characterize their functioning:

• Combustion way: spark-ignition engine and compression-ignition engine

• Cycle duration: four-stroke engine and two-stroke engine

• Fuel feeding: direct injection and indirect injection

• Air supply: naturally and supercharged

• Cooling system: air cooling and liquid cooling

The features of the engine Fiat punto 1.2 8V in this thesis:

• Spark-ignition engine

- Four- stroke engine and the volume of cylinders of the engine is 1.2 (l=litters)

- Indirect injection which the carburetion and fuel-injection into the manifold.

- Naturally air supply

- Liquid cooling system

2.1 Four-stroke spark-ignition combustion engine

In this sub-chapter, the basic knowledge of the four-stroke spark-ignition combustion engine is going to be expounded separately.

2.1.1 Features of the combustion process

At first, the combustion process in the spark-ignition engine is going to be introduced.

In the combustion process, the fuel and air are mixed in the intake system, together go through the intake valve in to the cylinders, then compressed. In the end of the compression stroke, the combustion starts at the spark plug by an electric discharge.

Following inflammation, a turbulent flame develops, propagates through the essentially premixed fuel-air burned gas mixture until it reaches the combustion chamber walls and then extinguishes.

As the flame propagates across the combustion chamber, the unburned mixture ahead of the flame called end gas is compressed, then the pressure, temperature and density increase.

2.1.2 Four-stroke engine

A four strokes of the piston can help engine to complete a cycle and produce one power stroke. The piston moves between the top dead centre position (TDC) and the bottom dead centre position (BDC). The figure 2-1 shows working process of the four-stroke engine.
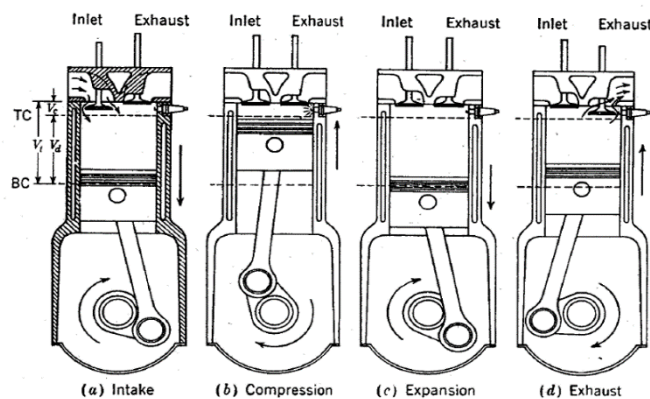
Figure 2-1 Four-stroke engine

- (a) Intake stroke: The piston moves from PDC to BDC and take fresh mixture gases into the cylinder. The inlet valve opens shortly before the stroke starts

- (b) Compression stroke: Both intake valve and exhaust valve are closed and the mixture gases inside the cylinder is compressed to a small fraction of its initial volume.

  Combustion: In the end of the compression stroke, the combustion initiates and the pressure in the cylinder rises rapidly.

- (c) Expansion stroke: The high temperature, high pressure gases push the piston toward to its BDC position and force the crank to rotate.

- (d) Exhaust stroke: The piston moves from the BDC position to the TDC position, and as the piston moves towards to the TDC, the burned gases are expelled. As the piston approaches the TDC position the intake valve opens. The exhaust valve closes just after TDC.

2.1.3 Spark-ignition

The petrol engine is called spark-ignition (SI) engine as well. After the suction stroke, the gas is compressed during the compression stroke and then before the piston arrives at the TDC, the spark plug fires and the fuel gets ignited in combustion stroke. The combustion takes place through the ignition, so it called spark-ignition engine.

2.1.3.1 Ignition-timing

Timing the ignition is important. Cause igniting at the right time can maximum the power and minimum the emissions, and the following equation is going to illustrate the importance of the ignition-timing.

Work is the product of force and distance:

$$W=F*L$$

In the cylinders, the force is product of the pressure and the area of piston:

$$F=P*S$$

So, for a cylinder the work is:

$$W=P*S*L$$

In this equation, the distance is the length of the cylinder. It is easily to see that in the cylinder the area of the piston and the length are fixed, so the only way to maximize the work is by increasing the pressure in the cylinder.

There is always a small delay of the spark time when fuel/air mixture burns and the pressure in the cylinder reaches its maximum. If the spark occurs right when the piston

arrives at the TDC, the piston must already move down a little distance to the BDC, before the gases reach in the highest pressure.

In order to make the best use of the fuel, the spark should occur before the piston reaches the TDC. The time of the fuel burning is constant, but with the engine speed increases, the speed of the piston must increase as well. In the other words, the more engine speed, the more spark advance is required.

2.2 Engine starter

In order to make the engine start. The engine must be turned at some speed at the beginning, so that the engine can suck fuel and air into the cylinders then compress them. A powerful electric motor finishes this job and it carries a small pinion (gear wheel) which engages with a large gear ring around the rim of the engine flywheel. So that the engine starter needs a heavy electric current from the thick wire through the battery. The figure 2-2 shows the structure of the engine starter.
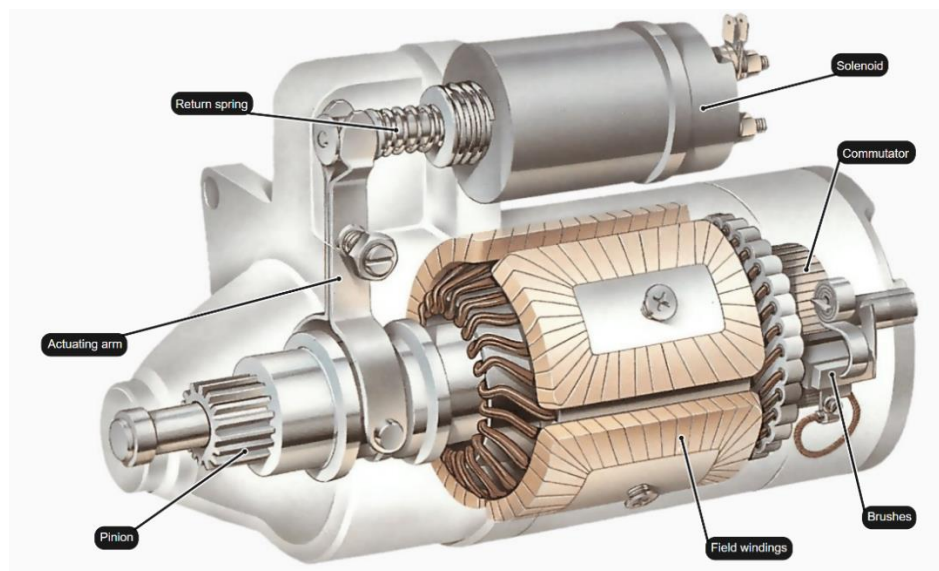
Figure 2-2 Engine starter and its structure

It obviously that the engine starter will have the same speed as the engine when engages with the engine, and then the engine may spin the starter too fast to make the engine starter badly damaged. In order to avoid the damage, the starter itself has a device named the Bendix gear, this Bendix gear could engage its pinion with the gear ring on the flywheel only while the starter turns the engine. It disengages as soon as the engine picks up speed.

Chapter3 Engine test stand design

In order to take the engine outside a real car, the test stand design and building is the first step in this project. There are three key points to be considered:

- The material of the engine stand

- The dimension of the engine stand

- The shape of the engine stand

3.1 Material of the engine stand:

After discussing with the supervisor, the steel is used as the material of the engine stand. The advantages of the steel are:

- A good conductor, the whole stand can look as the same groud point

- Good plasticity, easy processing

- Highly durable metal, good toughness

- High temperature resistance, oxidation resistance

3.2 Dimension of the engine stand:

The engine model is Fiat punto 1.2 8V. We can easily measure the dimension of the engine with the meter ruler. While for a test stand, it must a bit larger than the engine, because people who works with the engine test bench must have enough flexible space to fix the engine on the stand. But if the dimension of the engine stand is much larger than the requirements, it will cause the unnecessary expenses.

The dimension of the engine we decided is 75cm X 80cm (Figure 3-1).
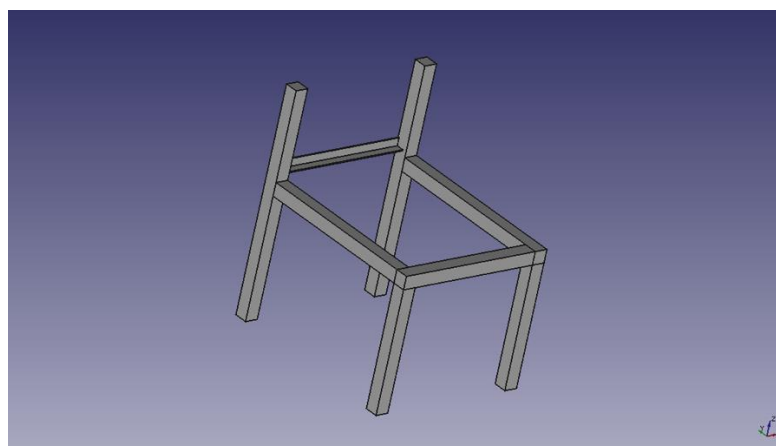
Figure 3-1 Initial design of the test-stand

3.3 Shape of the engine test stand:

The shape of the engine test stand is modifying with the program going.

- In order to put the battery on the stand, the bottom beam is added.

- As the electric part building, the top beam is added for putting the relay, the fuses and the common nodes on the engine test stand.

- The control panel is necessary for a test bench, the indicated lamp, the control button need to put in the panel, the drilled holes can put these parts on the test bench.

So, the final design of the engine test bench shows as the figure 3-2:
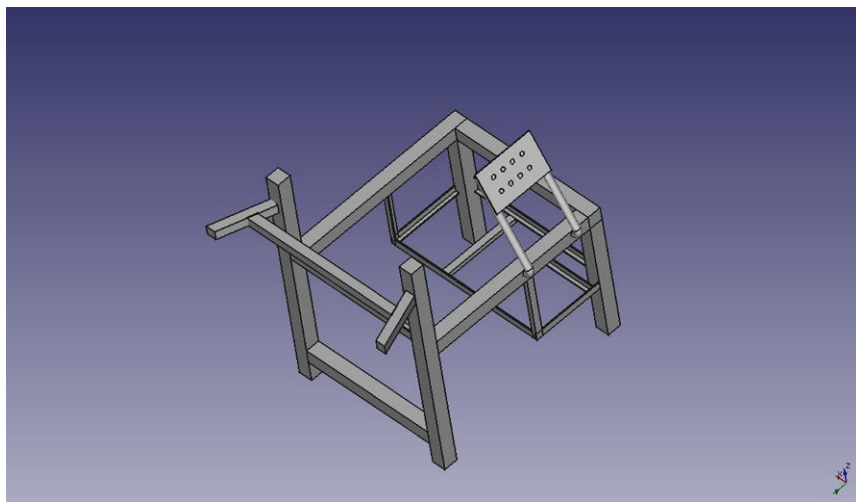
Figure 3-2 Final design of the test stand

Chapter4 Engine preparation

Since the engine is an old one, it must have a lot of rust between the closed surface, the engine sealing rings are also ageing. It is necessary to clean and repair it at the beginning of the project. This kind of repairing can avoid the leakage after injecting the gasoline. Make sure the engine works in a good condition is the first part of the chapter will illustrate. Second, checking the sensors working status is also important. Making sure that all the sensors have a good working condition can save a lot of time for the final inspection and easier to troubleshoot when the trouble occurs.

4.1 Disassemble and clean the engine

With the supervisor Massimo and one of his student's help, we disassemble the engine and studied the engine structure and understand the engine working principle. Then cleaned all the parts of the engine. At last, studied how to reassemble the engine.
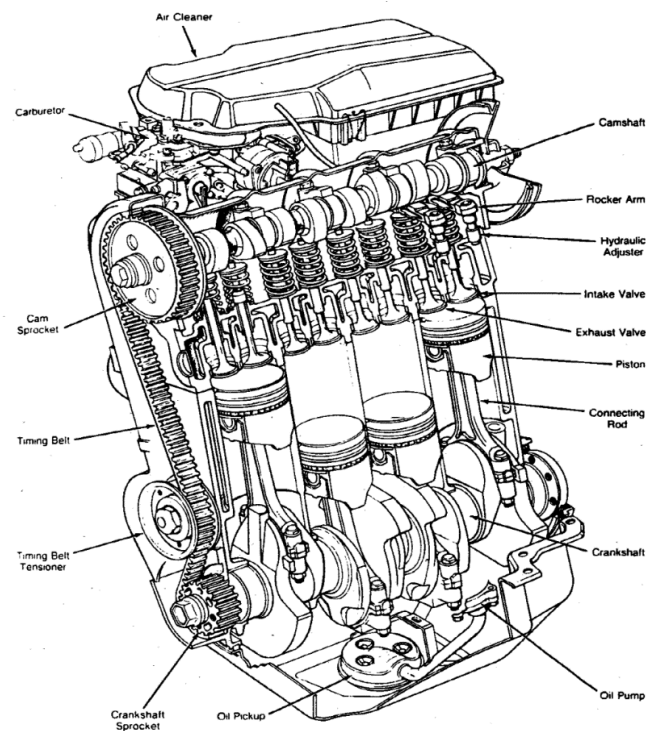
Figure 4-1 Basic geometry of reciprocating internal combustion engine

Automotive 4stroke, SI, naturally aspirated, carburetted, engine

There are three different ways to clean the engine:

• For the Stubborn oil pollution in the fine surface, using the air pressure with gasoline machine to clean. (Figure 4-2)

• For the rust in the screws, using wire wheel to clean. (Figure 4-3)

- For the little, easy clean component, just using the gasoline with the hard brush and tissue to clean. (Figure 4-4)

- For the rust between the covered surface, using the file to clean. (Figure 4-5)

Figure 4-2 Clean the stubborn oil pollution with air pressure and gasoline

Figure 4-3 Clean the rust in the screws with wire wheel
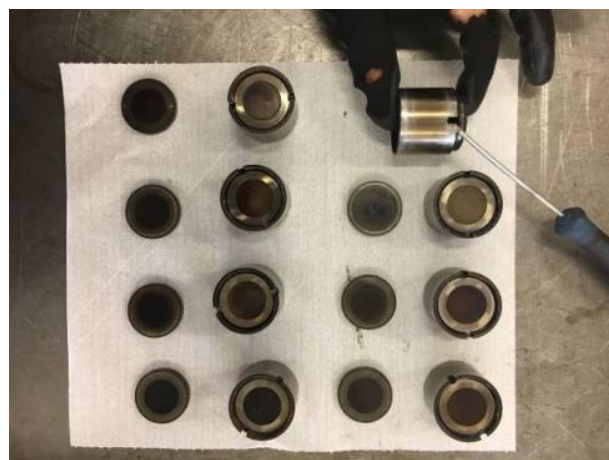
Figure 4-4 Clean the little oil pollution with clean tissue

Figure 4-5 Clean the rust surface with file

Figure 4-6 Gasket should be changed

The figure 4-6 shows the gasket in the engine.

4.2 Engine sensors

Since the funds is limited in the project. The sensors are also taken from the old engines. So, the sensors should be checked before mounting them to the engine. Making sure that all the sensors have good working condition.

The sensors we should check are:

• The knock sensor

• The temperature sensor

• The Lambda sensor

• The RPM sensor

• The TDC sensor

• The throttle position sensor and the closed throttle position sensor

• The absolute pressure sensor

4.2.1 Knock sensor

4.2.1.1 Introduction of the knock sensor

Some of the end-gas fuel-air mixture may undergo chemical reactions prior to normal combustion. The product of these reactions may then auto ignite i.e. spontaneously and rapidly release a large part of their chemical energy. This phenomenon of abnormal combustion is addressed to as knock.

In order to sense vibrations caused by engine knock or detonation, the knock sensor (Figure 4-7) is located on the engine block, cylinder head or intake manifold. The PCM uses this signal to alter the ignition timing and prevent detonation. It will compare this information with its pre-set tables to identify a valid knock or ping. If a ping is sensed, it will retard the ignition timing to protect the engine from this damaging pre-ignition. The knock sensor of the engine Fiat punto 1.2 8V is located at the bottom of the intake manifold.

The knock sensor is a piezoelectric sensor that contains a piezoelectric sensing crystal and a resister. This crystal creates a small amount of voltage when it shakes. In the figure 4-7, shows the photo that the knock sensor which is going to be used in the thesis. And the figure 4-8 shows the schematic of the knock sensor.

Figure 4-7 Knock sensor
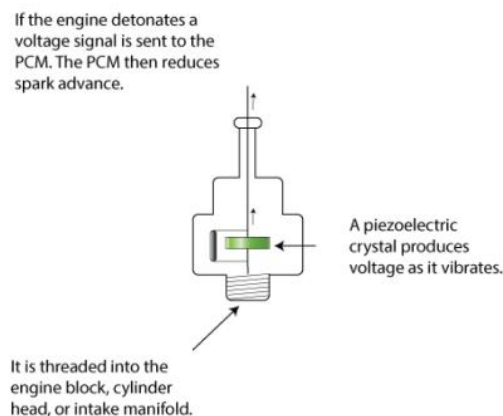
Figure 4-8 Schematic of knock sensor

4.2.1.2 Knock sensor working condition

The figure 4-9, shows the pin of the knock sensor, and the hand book of the sensors gives the right range of the resistance of the sensors. In order check it whether has a good working condition, the resistance between the pin B8 and pin B15 is going to be measured. If the resistance between these two points is in the range that the hand book provided, it is useable theoretically.
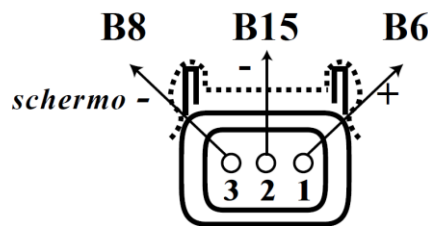
Figure 4-9 Pin of the knock sensor

The table 4-1 shows the reference resistance value and the measured resistance between the pin 2 and pin 3

The reference resistance of the knock sensor	The measured resistance of the knock sensor
From 530Ω to 580Ω	50KΩ

Table 4-1 Referece resistance and measured resistance of the knock sensor 1

From the first measurement, it is obviously that the first sensor which the resistance is 50KΩ, and it is not in the range that the hand book offered, so the second sensor is going to be measured. The table 4-2 shows the second knock sensor's resistance.

The reference resistance of the knock sensor	The measured resistance of the knock sensor
From 530Ω to 580Ω	500KΩ

Table 4-2 Referece resistance and measured resistance of the knock sensor 2

From the table 4-2, the second resistance of the knock sensor is 500kΩ, neither not in the range. Then we tested the third, and the third resistance neither in the range that the hand book provided to us.

Then we suppose that there is something wrong with the value that the hand book provided. So, the one with the closest value of resistance (the first knock checked) is used in the project, in order to avoid mistakes, we also checked the other materials about the knock sensor.

From the other material, it shows that when the knock sensor works well, the signal between the two pin 1 and pin 2 will get waveform like the figure 4-10.
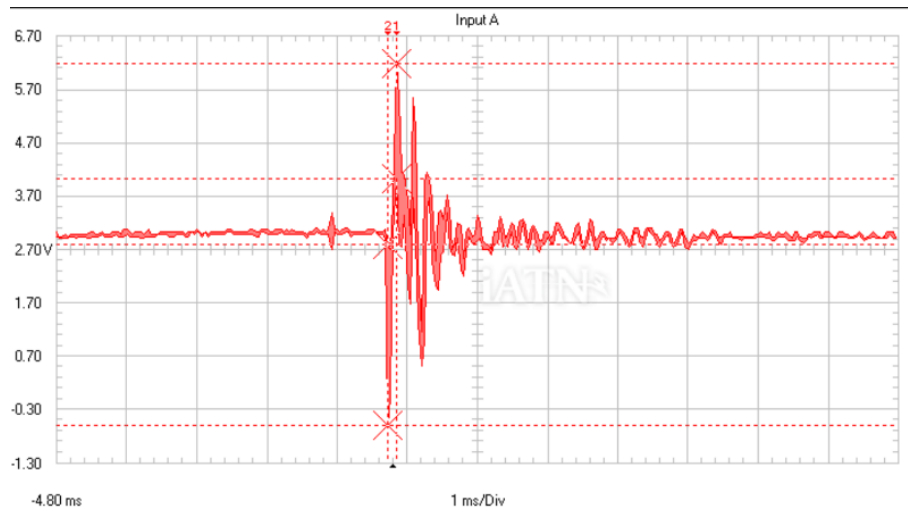
Figure 4-10 Reference waveform of knock sensor

After connecting the sensor to the circuit, through the oscilloscope we get the waveform when we beat it. The real waveform is showed in figure 4-11. It is obviously that the waveform of the knock sensor is almost same as the one showed in figure 4-10. So, we suppose the knock sensor has a good work condition and it can be mounted in the engine.

Figure 4-11 Real waveform of the knock sensor

4.2.2   Temperature sensor

4.2.2.1 Introduction of the temperature sensor

The temperature sensor measures the engine coolant temperature accurately, thereby, it can give an indication of the temperature of the engine. The figure 4-12 shows the temperature sensor which is going to be mounted on the engine in this thesis.

Figure 4-12 Temperature and the absolute pressure sensor

The engine temperature sensor is a type of sensor that its resistance changes with temperature. Many critical engine functions depend on the temperature of the engine, such as selection of air-fuel ratio, fuel injection timing, ignition timing etc. A cold engine requires rich air-fuel mixture; whereas the engine running at optimum operating temperature requires a lean mixture.

The engine temperature sensor informs the engine's ECU about the current and ongoing variations in the engine temperature. ECU, adjusts and regulates the fuel quantity and ignition timing. The engine temperature gauge on dashboard can get the data from engine temperature sensor. Based on this data, the ECU also controls the additional functions such as switching on or off the engine cooling fan (in this thesis the engine cooling fan switch on at 96°C).

The engine temperature sensor is located in the coolant pipe, below the air intake pipe and behind the right cylinder head. It is integral with the engine absolute pressure sensor. The figure 4-13 shows where is the temperature sensor located on the engine.
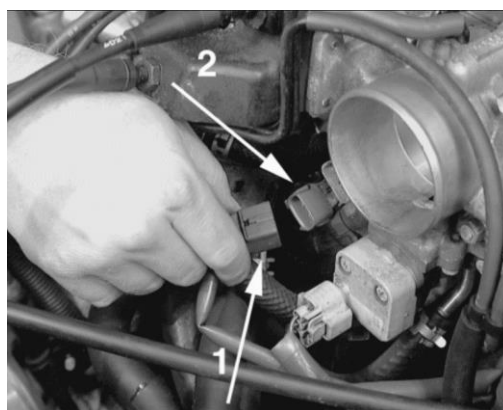
Figure 4-13 Location of the temperature sensor

4.2.2.2 Temperature sensor working condition

Same as the knock sensor, in order to check the temperature working condition, the resistance of the temperature sensor should be measured as well. The pin of the temperature shows in figure 4-14, the pin a and pin c are the two pins that represent the temperature sensor. And the pin c and pin b are the absolute pressure sensor. In order to

check the resistance of the sensor, the resistance between pin a and pin c are going to be checked.
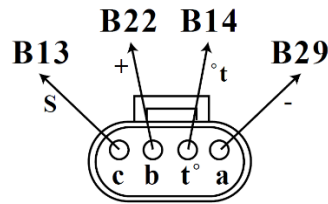
Figure 4-14 Pin of the temperature sensor

(between the pin a and pin c)

Table 4-3 shows the reference resistance value between the pin a and pin c, we can discover that the resistance of the temperature sensor changes with the temperature changing.

The temperature	The reference resistance value of the temperature sensor
0°C	9.5KΩ
10°C	3.8 KΩ
20°C	2.5 KΩ
60°C	500Ω
80°C	300Ω
90°C	200Ω

Table 4-3 Reference resistance of temperature sensor

The room temperature is 23°C, and the resistance of temperature sensor that tested in the project is 2.9kΩ, so this one can be mounted to the test bench.

The resistance of the temperature sensor changes with the temperature changing. It is not hard to find that the temperature sensor is a Negative Temperature Coefficient (NTC) thermistor. With the temperature increasing, the resistance of the temperature sensor goes down. The figure 4-15 shows an example signal of the temperature between the pin a and pin t°. This phenomenon can clearly to show in the figure. From the figure, we can easily to see that temperature goes up the voltage on the temperature goes down.
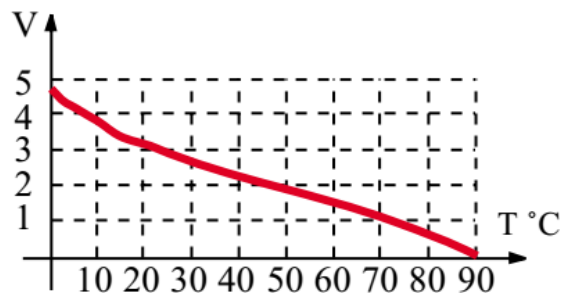
Figure 4-15 An example voltage on the NTC temperature sensor

4.2.3 Lambda sensor

4.2.3.1 Definition of the Lambda (λ)

- The theoretical amount of air that fits inside the cylinder at the normalized pressure

  p0 = 1.013 bar, is: $m_{a,th} = \rho_0 \times V_d$, where $\rho_0 = 1.29 \, kg/m^3$, and V_d is the cylinder displacement volume.

- Relative air supply is:

$$\lambda_a = \frac{m_a}{m_{a,th}}$$

- The relative fuel supply λ_f is defined as the ratio of the measured fuel mass m_f to the theoretical one $m_{f,th}$:

$$\lambda_f = \frac{m_f}{m_{f,th}}$$

- The theoretical fuel is the mass of fuel for an ideal stoichiometric combustion with the oxygen, and the stoichiometric ratio is:

$$L_{st} = \frac{m_{a,th}}{m_{f,th}}$$

And the stoichiometric ratio depends on the considered fuel, as the table 4-4 shows,

fuel	gasoline	diesel	LPG	methane
L_{st}	14.66	14.5	15.5	17.4

Table 4-4 Value of the stoichiometric ratio

- The air-fuel ratio (AFR) Lambda (λ) is defined as:

$$\lambda = \frac{\lambda_a}{\lambda_f} = \frac{m_a}{m_{a,th}} \times \frac{m_{f,th}}{m_f} = \frac{1}{L_{st}} \times \frac{m_a}{m_f}$$

An ideal stoichiometric combustion gives the $\lambda = 1$. For the SI engine, λ is controlled by λ_a, by throttling the air flow, consequently the λ_f is regulated by the engine management system.

- Lean operation: $\lambda > 1$, reduced λ_f.

- Rich operation: $\lambda < 1$, increased λ_f

4.2.3.2 Introduction of the Lambda sensor

The three-way catalyst (catalytic converter) is a most popular method used by the ve-hicle manufacturers to reduce the engine emissions. This device can convert the three toxic gases produced by the engine (carbon monoxide (CO), oxides of nitrogen (NOx), hydrocarbons (HC)) to considerably less harmful, non-poisonous gases (carbon dioxide (CO_2), water (H_2O) and nitrogen(N_2)).

In order to make the conversion of the gases efficient, the catalyst should operate within a certain temperature range, but also should be provided the exhaust gases that are within a certain very tight tolerance dependant predominantly on air/fuel ratio. This kind of precise control required the gas oxygen (Lambda) sensor installed upstream of the catalyst to provide to the operating system. The Lambda sensor has the ability of measuring the air/fuel present in the exhaust gases precisely. And send the result to the control unit. The Lambda sensor is showed in the figure 4-16.

Figure 4-16 Lambda sensor

To improve the exhaust emission, most of the vehicles produced after year 2000, add an additional Lambda sensor, it is fitted down-stream of the catalyst that monitors the performance of the catalyst itself.
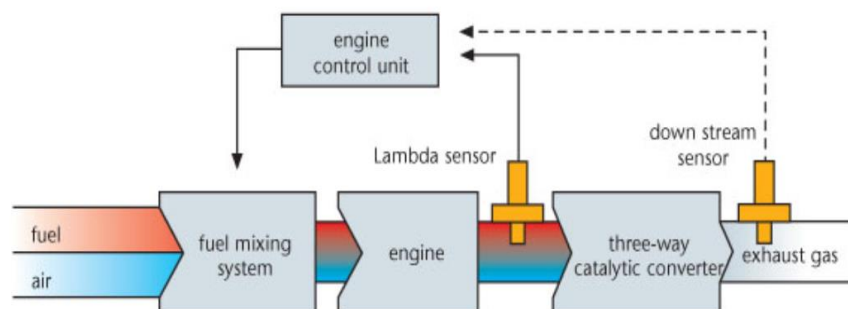
Figure 4-17 Location of the Lambda sensor

In this project, the Fiat engine 1.2 8V engine is used in the first generation of the Fiat car from the year 1993 to 1999, before the 20th century. So, only one upstream Lambda sensor is used in the engine. The figure 4-18 shows the location of the Lambda sensor on the engine. The red point is the Lambda sensor.
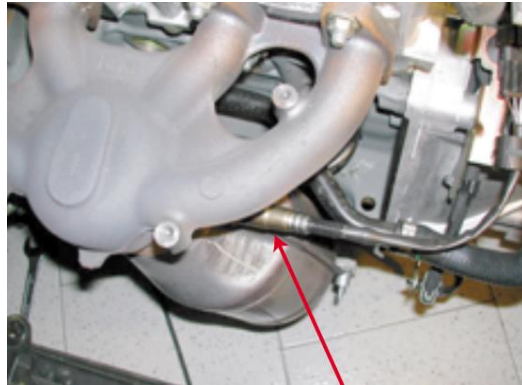
Figure 4-18 Location of the Lambda sensor on the engine

4.2.3.3 Lambda sensor working condition
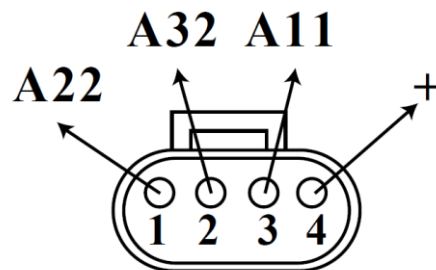
Figure 4-19 Pin of the Lambda sensor

(wire's colour:1. white 2. purple 3. brown 4. brown)

The figure 4-19 shows the pin of the Lambda sensor. The pin 4+ and 3- are the pins of the sensor's power supply. The pin 1 and 2 are the signal pins, if the temperature is lower than 300℃, we can not get any signal from them. Our checking is in the room temperature which is 23℃. So, in order to check the working condition of the lambda sensor, we can only check the resistance value between the pin 3 and pin 4, and got the following results shows in table 4-5.

The reference resistance value of Lambda sensor	The measured resistace value of Lambda sensor
3Ω	2.9Ω

Table 4-5 Reference and the measured resistance of the Lambda sensor

From the table 4-5, the hand book shows the sensor's static resistance is 3Ω. And in the test, the value of our Lambda sensor is 2.9Ω, we can mount it to the engine.

An example Lambda sensor signal between the pin 1 and pin 2 shows in figure 4-20.
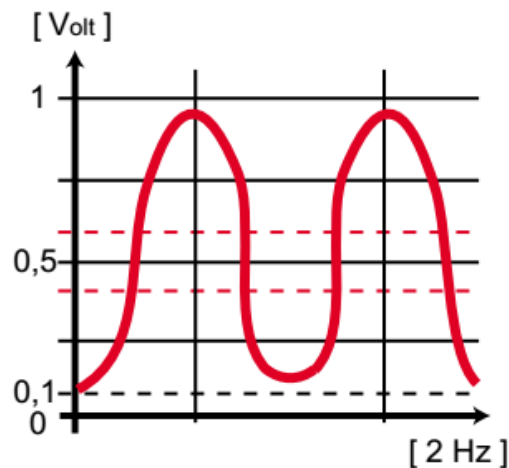
Figure 4-20 An example signal of the Lamda sensor

The value of the air/fuel ratio can be reflected from the signal of the lambda sensor, the table 4-6 shows the mixture condition that can be read from the signals.

The mixture condition	The voltage range ofthe signal
The ideal operation	0.4~0.7V
The reach operation	0.7~0.9V
The lean operation	0.1~0.4V

Table 4-6 Mixture condition from the signals of the Lambda sensor

4.2.4 RPM sensor

4.2.4.1 Introduction of the RPM sensor

The RPM (revolution per minute) sensor attaches near the engine crankshaft of a car's engine which is measure the speed of the crankshaft spins.

The RPM sensor typically have two types: inductive type and hall type. In the thesis an inductive sensor is used. These two types of RPM sensor working principle are going to be introduce as follow:

• The inductive RPM sensor introduction:

The inductive RPM sensor is a pickup sensor, the sensor's coil produces an oscillating voltage as the result of the inductive effect. (For example: the sinusoidal wave (~AC voltage)). The magnetic field surrounding the coil changes when the wheel's teeth passes to the pole pin of the sensor in an enough close distance. The voltage induces with the magnetic field changing which is proportional to the strength and rate of change of the magnetic field.
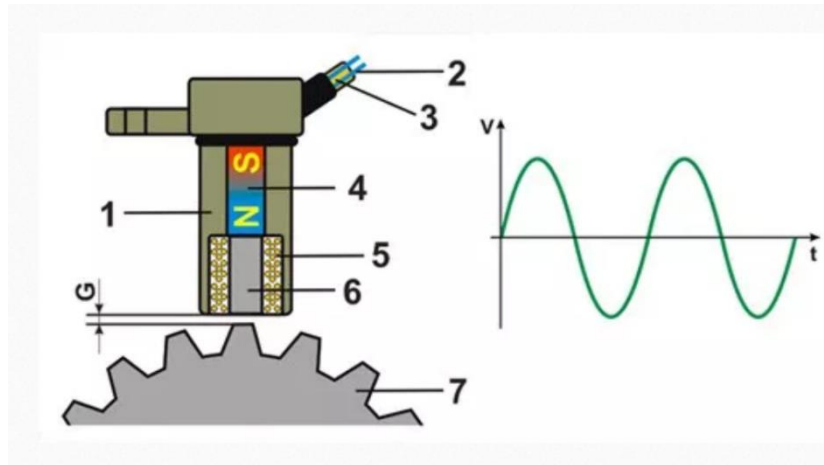
Figure 4-21 Basic integral component of the inductive RPM sensor and generated signal

1. Sensor housing 2. Output signal wires 3. Coaxial coated protection 4. Permanent magnet 5. Inductive coil 6. Pole pin 7. Trigger wheel G. Air gap

The voltage signal produced by the sensor is depending on the speed of the wheel and the number of turns of the coil. During the engine cranking the voltage can be expected between 1V and 2V. And during the higher RPM can expect more voltage. The signal produced by the sensor is weak and easily degraded by the other external signal, so usually shielded with a coaxial coated wires type as the protection.

- The hall effect RPM sensor introduction:

The output signal from the hall effect RPM sensor is in the range of milli voltage and is additionally amplified by integrated electronics which is fitted inside of the sensor housing. The output voltage singals usually in digital waveform (square form), and after the amplification, the output peak voltage can up to 5V (positive or negative). The amplitude of the output signal remains constant, only the frequency increases proportionally with rpm. Different from the inductive sensor the hall effect RPM sensor need an external supply voltage for the integrated electronics. Usually the voltage is 5V (+Vcc), in some cases it can be 12V.
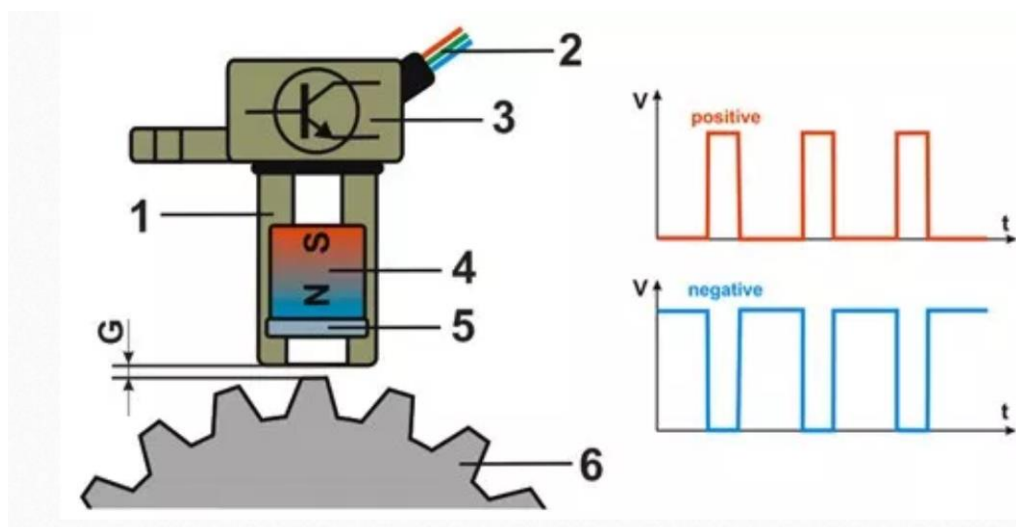
Figure 4-22 Typical build of the hall effect RPM sensor and generated signal

The figure 4-23 shows the photo of the RPM sensor which is going to be used in the project.

Figure 4-23 RPM sensor

4.2.4.2 RPM sensor working condition

In order to check the RPM sensor whether has a good working condition, the resistance of the sensor should be check as well, the figure 4-24 shows the pin of the RPM sensor. And the pin 1 and pin 2 will gives us the resistance of the RPM sensor, the pin 1 and pin 3 can gives us the signal of the RPM sensor.
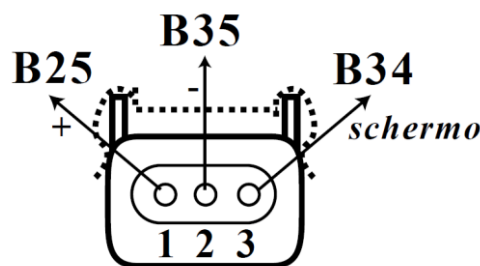
Figure 4-24 Pin of the RPM sensor

The electrical resistance depends upon the manufacture application and the type of the sensor. Typically, it is in the range of 500Ω-1500Ω. In the sensor's hand book which the Fiat provide to us the reference resistance of the RPM sensor is in the range from 1100Ω to 1400Ω. After the test, the resistance between the pin 1 and pin 2 is 1127Ω, so it can be used in the bench.

The reference resistance of the RPM sensor	The measured resistance of the RPM sensor
From 1100Ω to 1400Ω	1127Ω

Table 4-7 Reference resistance and measured resistance of the RPM sensor

The crankshaft reluctor wheel is fixed with the crankshaft. With the rotation of the crankshaft, the teeth in the reluctor can cause the inductor RPM sensor senses the magnetic field changes. And in the crankshaft, there is always have one or more missing teeth to provide the engine crankshaft position to the ECU. The figure 4-25 shows the reluctor wheel in the engine Fiat Punto 1.2 8V, it is not hard to see that there are 2 missing teeth and has the other 60-2=58 teeth averagely distributed on another $\frac{14}{15}\pi\ rad$ plane.

Figure 4-25 Crankshaft reluctor wheel with 2 missing teeth

After studied the working principle of the RPM sensor, we can easily to know these two missing teeth can trigger a larger signal of the RPM sensor. The figure 4-26 shows an example signal which is the RPM sensor displayed.
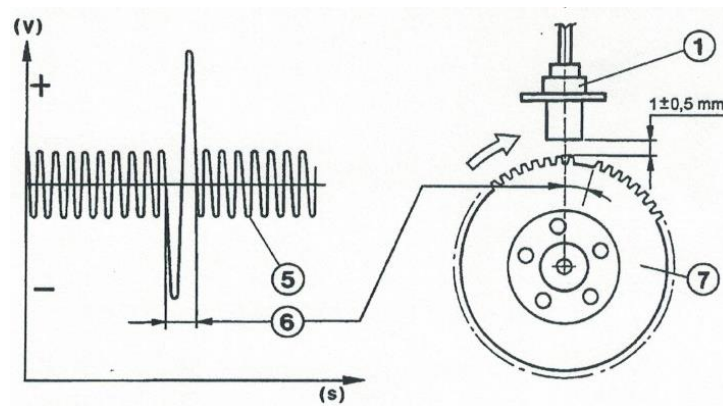
Figure 4-26 An example RPM sensor signal with the missing teeth

The following table 4-8, illustrate the meaning of each part of the figure 4-26:

Serial Number	The meaning of the number in the figure
1	RPM sensor
5	Output signal
6	Signal corresponding to the two missing teeth
7	Crankshaft pulley with phonic wheel

Table 4-8 The meaning of each part of the figure 4-26

4.2.5 TDC sensor

4.2.5.1 Introduction of the TDC sensor

The Top Dead Centre (TDC) is a reference point for the timing of a vehicle engine. It is defined as when the cylinder has risen to the top, the intake and exhaust valve both closed at the same time. The TDC sensor sends an impulse to the ECU to ensure that ignition time at the correctly time. Figure 4-27 shows the TDC sensor which is mounted on the test bench.

Figure 4-27 TDC sensor

4.2.5.2 TDC sensor working condition

The hand book doesn't provide us the reference resistance of the TDC sensor, so we can not check it through the reference resistance value. Since the TDC sensor is located at the top of the engine and it is easily to be mounted and un mounted, so we just put the TDC sensor to the engine and if it doesn't work, we can just change it directly.

The figure 4-28 shows the pin of the TDC sensor and the value of the resistance of the TDC sensor also has been test before mounting to the engine. The pin 1 and pin 3 are the testing pin for the TDC sensor resistance, and the pin 1 and pin 2 are the signal pins.
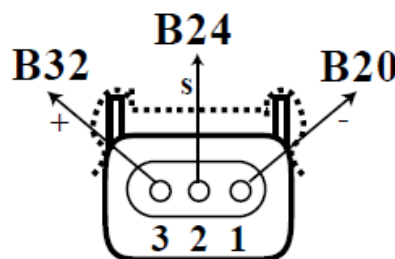
Figure 4-28 Pin of the TDC sensor

The resistance value between pin 1 and pin 2	The resistance value between pin 1 and pin 3
6.53MΩ.	258.8kΩ

Table 4-9 Measured resistance of the TDC sensor

The table 4-9 shows the measured resistance of the TDC sensor. The resistance between the pin 1 and pin 3 is 258.8kΩ, the resistance between the pin of 2 and the pin of 3 is 6.53MΩ.

The figure 4-29 shows the photo of the camshaft wheel of the engine Fiat Punto 1.2 8V. It has one large tooth and two short teeth raised in the edge of the wheel, the raised teeth help the TDC sensor to recognize the position of the camshaft position.

Figure 4-29 Camshaft wheel

The figure 4-30 shows an example signal waveform of the TDC sensor which has a good working condition between the pin 1 and pin 2.
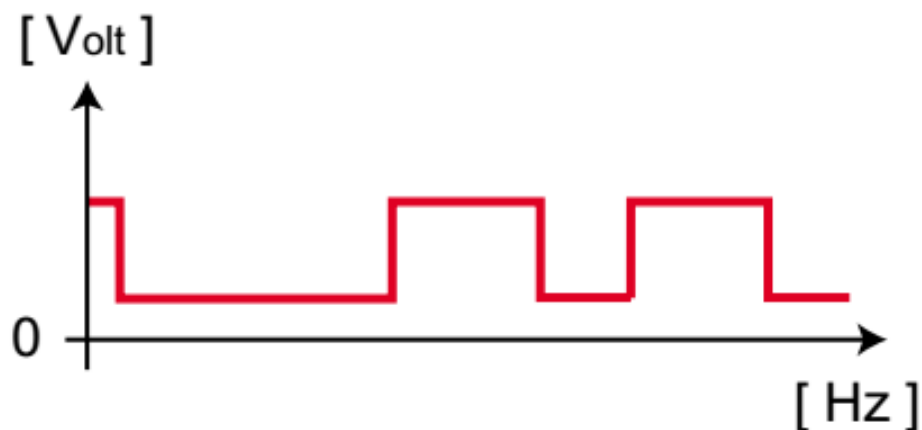
Figure 4-30 An example signal waveform of the TDC sensor

From the figure 4-30 there is one long high-level signal and two short high-level signals. The first short signal represented the first cylinder arrives at the TDC. From the TDC sensor we can know which of the cylinder is arriving at the TDC and then the TDC sensor can give a feed back to the injector to ignite the fuel.

4.2.5.3 TDC sensor and the spark advance

As we mentioned in chapter 3, in order to make the best use of fuel, the spark advance is required of the engine. The figure 4-31 show the relationship of the cylinder clycle, the crankshaft angle, the RPM sensor TDC sensor and the spark advanced.
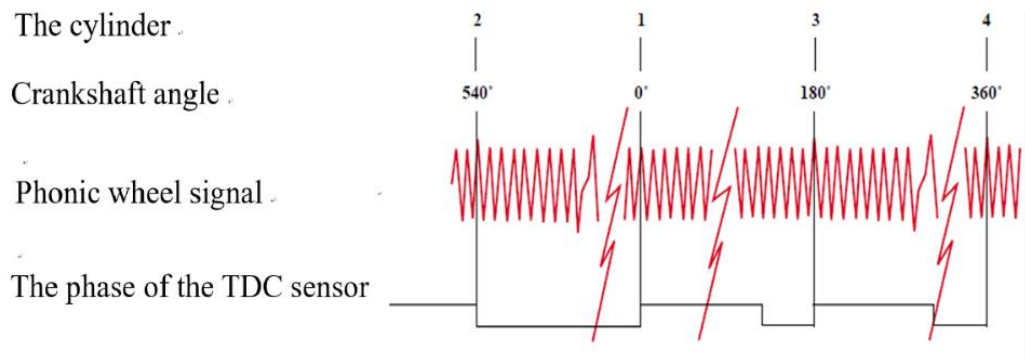
Figure 4-31 Signals relation between the TDC and the RPM sensors

From the figure 4-31, the first short rising edge representes the first cylinder arrives at the TDC, and the injector begins ignition a little before the first cylinder arrives at the TDC, the other cylinders are the same, before they arrive at the TDC, the ignition already triggered. And the ignition order of this engine is 4-2-1-3.

4.2.6 Throttle position sensor and closed throttle position sensor

4.2.6.1 Introduction of the TPS and the CTPS

Throttle position sensor (TPS) is usually located on the throttle valve spindle, so it can monitor its position directly. The TPS sensor is a kind of potentiometer, it provides a variable resistance depending on the position of the throttle valve. The ECU uses the signal from throttle position sensor as an input signal in the control system. The ignition timing and fuel injection timing and the other parameters are altered depending on the position of the throttle valve, but also depending on the rate of change of the position. The one is beside the throttle position sensor is the closed throttle position sensor which indicate that the throttle is completely closed.

As the photo shows in figure 4-32, the left top one is the throttle position sensor and the left bottom one is the closed throttle position sensor.
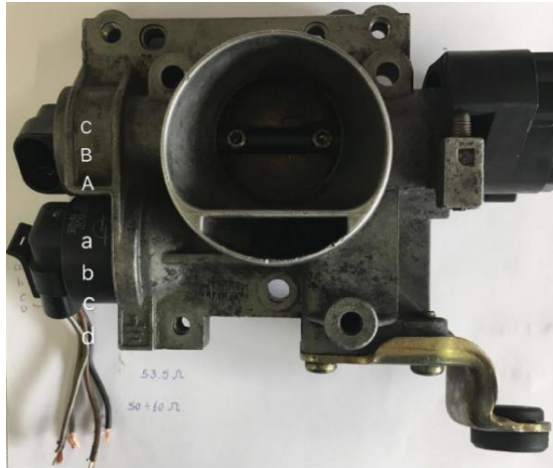
Figure 4-32 Throttle with the position sensor and closed throttle position sensor
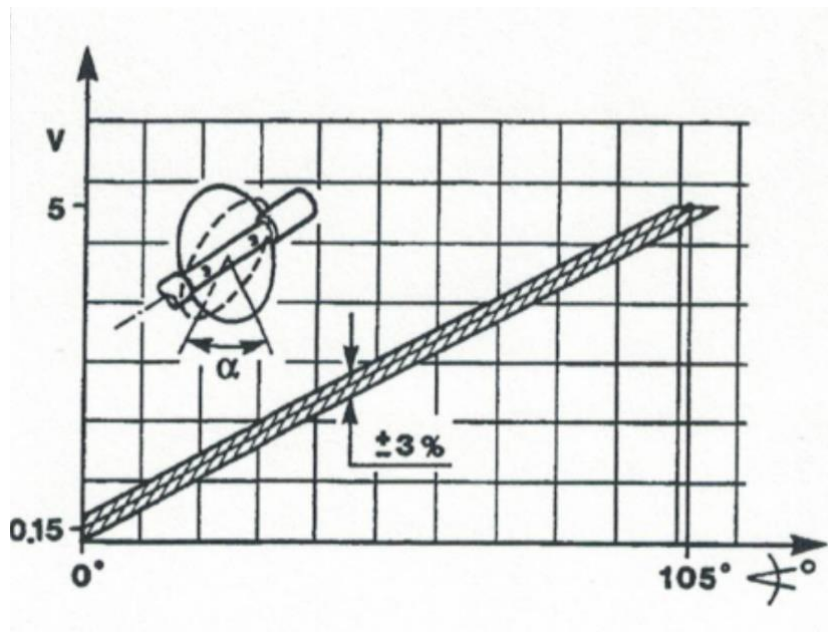
Figure 4-33 Voltage level supplied by the sensor as a function of throttle angle

As the figure 4-33 shows, the potentiometer is a signal ramp and its main specifications are:

- Effective electrical angle is: 90°±2°

- Mechanical angle is: 105°±4°

- Total mechanical travel is: 110°±8°

- Temperature service range is: -30°C~125°C

4.2.6.2 TPS working condition

The figure 4-34 shows the pin of the throttle position sensor, the pin 1 and pin 2 are the resistance test pins for checking the sensor working condition, and the pin 1 and pin 3 are the signal pins.
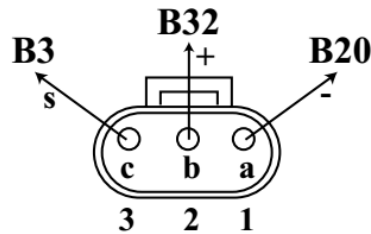
Figure 4-34 Pin of the throttle position sensor

The table 4-10 and the table 4-11 show the reference resistance and measure values with the throttle angle changing.

The reference resistance between the pin 1 and pin 2	The measured resistance between the pin 1 and pin 2
1200Ω~1250Ω	1167Ω

Table 4-10 Reference and measured resistance between pin 1 and pin 2

The degree of the potentiometer	The reference resistance between the pin 1 and pin 3	The measured resistance between the pin 1 and pin 3
0°	0Ω~1200Ω	1960Ω
45°	0Ω~1200Ω	3418Ω
90°	0Ω~1200Ω	2738Ω

Table 4-11 Reference and measured resistance between pin 1 and pin 3

From the table 4-10 and the table 4-11, the resistance between the pin 1 and pin 2 is not strictly in the range that the hand book provided to us, and the resistances between pin 1 and pin 3 are larger than the reference resistance. Then we checked the second one, the measured resistances are also not in the range.

Since the throttle is in the top of the engine and easy to change, and the variation between the measured value and the reference don't have a lot of different. We decided to use it in the test bench, if some problems occur, we can just change the other one to continue the thesis.

The resistance of the closed throttle position sensor also be tested. The resistances of them are showed in the table 4-12

The two pins	The reference resistance	The measured resistance
Pin A and pin D	50Ω~ 60Ω	53.5Ω
Pin B and pin C	50Ω~ 60Ω	53.4Ω

Table 4-12 Reference and the measured resistance of the colsed throttle position sensor

From the table 4-12, the measured resistance is strictly in the range of the hand book provides, so there is no problem of the closed throttle position sensor. It can be mount in the engine to do the test.

The figure 4-35 shows an example signal of the the closed throttle position sensor in a good working condition.
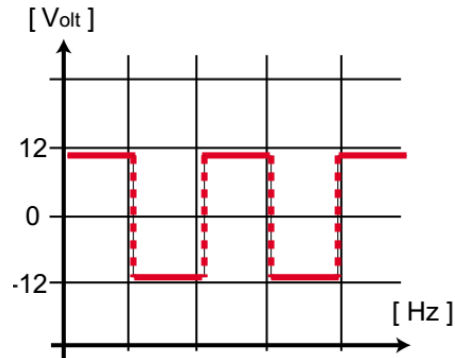
Figure 4-35 An example signal of the colsed throttle position sensor

4.2.7 Absolute pressure sensor

4.2.7.1 Introduction of the absolute pressure sensor

The intake manifold pressure sensor is a sensor that measures the negative air pressure inside the intake pipe, after it passes the throttle valve. The pressure value is recorded by an evaluation circuit, via the differential pressure of two diaphragm pressure chambers. With the air pressure data, the engine management can calculate the turbo boost pressure for turbocharged engines and the fuel injection values for naturally aspirated engines.

The pressure sensor can defective intake manifold. The engine management system can diagnostic trouble code and ignite the check engine light. In addition, if the engine lacks power, it can use more fuel or even go into emergency mode. The figure 4-36 shows the photo of the temperature and the absolute pressure sensor.

Figure 4-36 Temperature and the absolute pressure sensor

4.2.7.2 Absolute pressure sensor working condition

The figure 4-37 shows the pin of the temperature and the absolute pressure sensor, which the pin c and pin b are the two pins of the absolute pressure sensor. Since other two pins are the temperature sensor we have tested before, and there is not an accurate reference of the absolute pressure sensor we also suppose it has a good working condition and can be mounted to the engine. If some problems occur in the test, then we can change it.
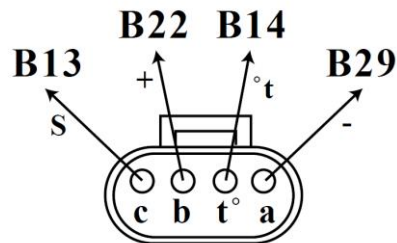
Figure 4-37 Pin of the absolute pressure sensor

(pin c and pin b)

4.3 Actuators

The actuators we should check are:

* The injector

* The vapor canister

* The transformer of the engine

* The gasoline-pump

4.3.1 Injector

4.3.1.1 Introduction of the injector

The injector is an electric valve that supplies the pressurized fuel by the fuel pump in a car. It is capable of opening and closing many times per second. The ECU controls the injector' s pulse width that determine the fuel injector stays open to change the amount of fuel supplied to the engine.

When the injector received the signal from ECU, the injector is energized and the electromagnet moves the plunger then the valve opens, the pressurized fuel to squirt out through the tiny nozzle. The nozzle can atomize the fuel, the fuel becomes a mist, so it can burn easily. The figure 4-38 shows the inside structure of the injector. The figure 4-

39 shows the four injectors we are going to use in the thesis, and we order it from the left to right as $1^{st}, 2^{nd}, 3^{rd}, 4^{th}$.
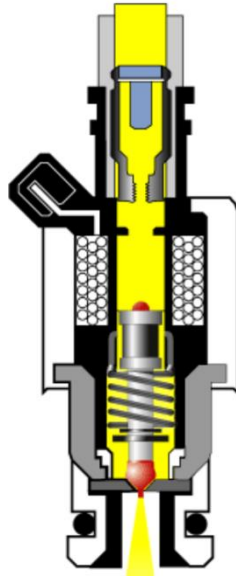
Figure 4-38 Inside of the injector

Figure 4-39 Four injectors to be mount in the engine

4.3.1.2 Injector working condition

The same as the sensors, the working condition of the actuators also should be tested before mounting them to the engine to reduce the trouble when we start the engine and easy troubleshoot the problems.

The hand book also provides the static resistance of the injector, and the measured resistance are showed in the table 4-13:

The injector's number	The reference resistance of the injector	The measured resistance of the injector
1st	14Ω~16Ω	15.1Ω
2nd	14Ω~16Ω	14.9Ω
3rd	14Ω~16Ω	15.0Ω
4th	14Ω~16Ω	15.0Ω

Table 4-13 Reference and measured resistance of the injectors

From the table 4-13, all the injectors static resistance measured are in the range of the reference value, so all of them can be used in the project.

The figure 4-40 shows an example signal of the injectors.
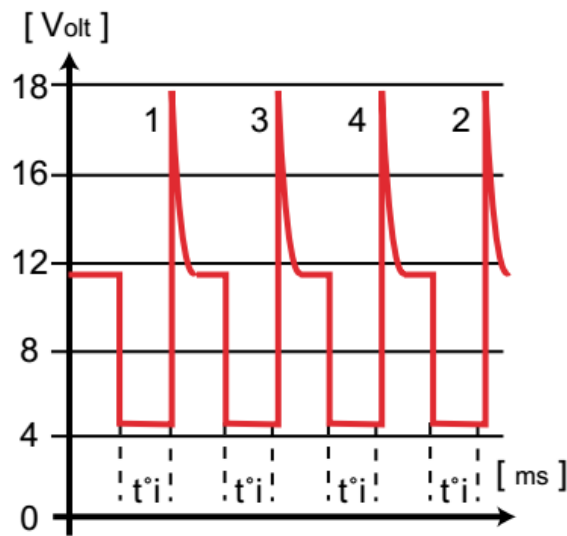
Figure 4-40 Example signal of the injectors

4.3.2 Vapor canister

4.3.2.1 Introduction of the vapor canister

As we know, there is a lot of emissions come from the evaporating out of the tank. The vapor canister is the canister which is collect the fumes and the carbon from the combustion engine. Then pump them into the engine and burn off. And it can pressurize the tank and avoid the further fuel evaporation and locking the moisture. The vapor canister is near the fuel cap. It can make the fuel system last longer and prevent a lot of smog. The figure 4-41 shows the photo of the vapor canister used in the thesis.

Figure 4-41 Vapor canister

4.3.2.2 Vapor canister working condition

The hand book also gives us the reference resistance of the vapor canister, so we can do the preliminary checking through the resistance of the vapor canister. The pin of the vapor canister shows in figure 4-42.
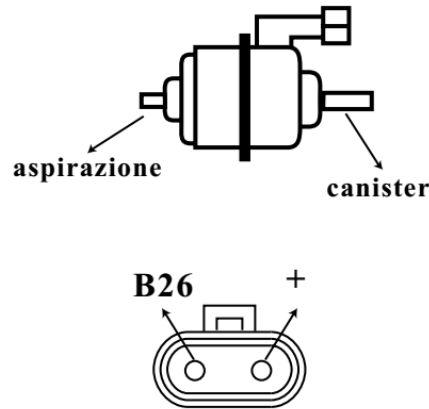
Figure 4-42 Pin of the vapor canister

The reference resistance of the vapor canister	The measured resistance of the vapor canister
35Ω~58Ω	17.9Ω

Table 4-14 Reference and measured resistance of the vapor canister 1

From the table 4-14, the measured resistance of the vapor canister is a bit far from the reference, so the second vapor canister is going to be checked, and the second measured result shows in table 4-15.

The reference resistance of the vapor canister	The measured resistance of the vapor canister
35Ω~58Ω	37Ω

Table 4-15 Reference and measured resistance of the vapor canister 2

From the table 4-15, the resistance of the vapor canister is in the range of the reference resistance, so the second one is chosen to mount to the engine.

The figure 4-43 shows an example signal of the vapor canister in a good working condition.
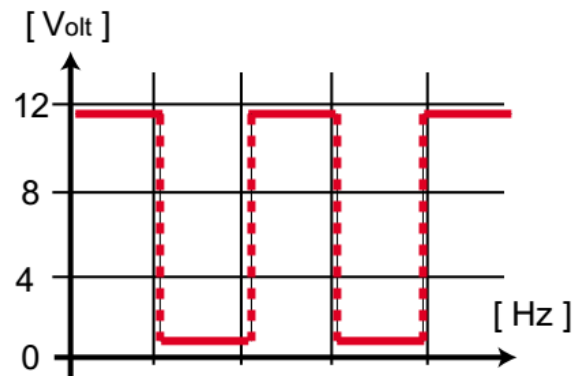
Figure 4-43 Example signal of the vapor canister

4.3.3 Two transformers of the engine

4.3.3.1 Introduction of the transformer

It is not difficult to see, there are two transformers beside the fuel cap. A transformer is a power transfer device. It transfers power from the primary winding to the secondary winding.

The two transformers in the engine provide the high voltage for the spark plug through transfer the low voltage into the high voltage. The figure 4-44 shows the transformer on the engine.
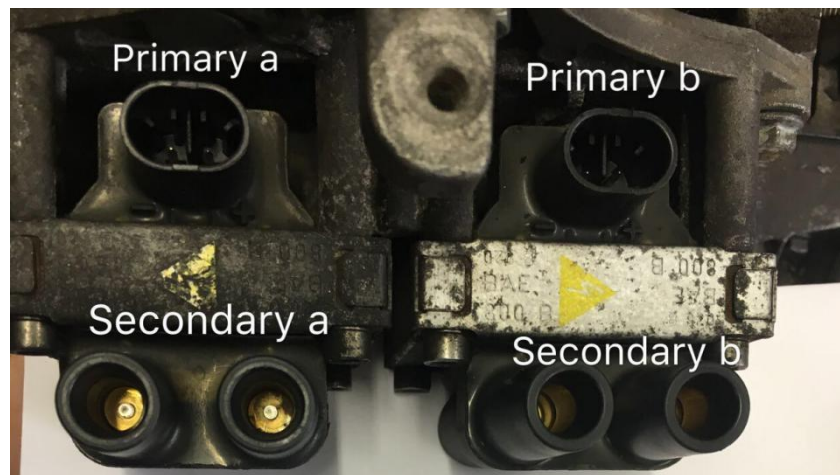
Figure 4-44 Transformer of the engine

As the photo shows in Figure 4-44, there are two transformers, one in the left and the other in the right. The two top big plug is connected to the primary windings and the four little plugs in the bottom are two the secondary windings which are connected to the spark plug part.

4.3.3.2 Transformers working condition

In order to check the wo transformer whether in a good working condition, we compared the static resistances with the reference resistances which are provided by the hand book

The table 4-16 shows the measured resistances and the reference resistances of the two transformers.

Number of the winding	The reference resistance	The measured resistance
Primary a	0.5Ω~0.65Ω	0.6Ω
Primary b	0.5Ω~0.65Ω	0.6Ω
Secondary a	6850Ω~7850Ω	7270Ω
Secondary b	6850Ω~7850Ω	7850Ω

Table 4-16 Reference and measured resistance of the transformers

From the results showed in the table 4-16, all resistances of the windings are in the range of the reference resistance that the hand book provided. So, both of the two transformers in the engine have a good working condition, and we do not need to change it.

4.3.4 Gasoline-pump

The gasoline pump pumps the gasoline from the tank to the injector rail. In order to check it whether has a good working condition, we just need to verify that does it can pump the gasoline.

A long tube is connected to the output of the pump, and then put the pump into a tank of water. Connect the pump power supply to the 12V battery. It begins to pump the water and the voice of its pumping process is normal, so the pump can be used in the project. The figure 4-45 shows the photo of the gasoline pump in this thesis.

Figure 4-45 Gasoline pump

4.4 Reassemble the engine.

After the cleaning and checking the all parts of the engine. With the supervisor's help the engine is reassembled by one of student the Filos. The figure 4-43 show the reassembled engine fixed in the test bench stand.

Figure 4-46 Engine body fixes on the test bench

Chapter5 Electric part of the test bench

After the mechanical part, the engine is already put in the designed engine test stand. But we can not run the engine only with the mechanical part, not to mention getting any measured signals through the sensors.

In order to run the engine, the next important step is connecting the electric circuits of the ECU with all the sensors and actuators, so that the ECU can control the engine runs and the signals from the sensors also can be obtained by the ECU. In this chapter, the electric part of the test bench is going to be introduced.

5.1 Electric circuit of the ECU

5.1.1 Introduction of the ECU

The controller used for this engine, is the Electric Control Unite (ECU).

ECU is a kind of electronic control unit that can control the engine running in the optimal performance when it is working. By reading signals from the sensors of engine, the ECU also can process the data with multidimensional performance maps, then gives the right command to the actuators.

The figure 5-1 shows the photo of the ECU in this project. The model of the ECU in this thesis is IAW 59F.

Figure 5-1 ECU
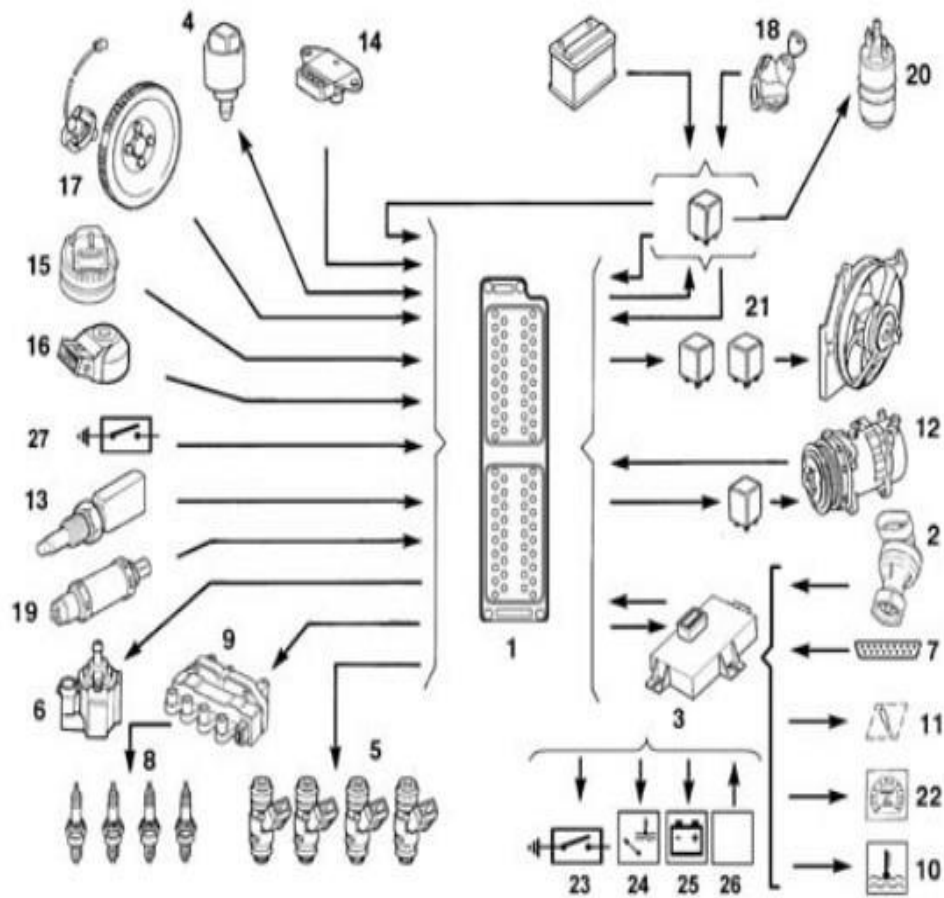
Figure 5-2 Sensors and actuators connected with ECU

From the figure 5-2, it is easy to see all the sensors and actuators connecting with the ECU, the name of each components in figure 5-2 presented in following table 5-1.

Number	Element
1	ECU
2	Oil pressure sensor
4	Idle step motor
5	Injectors
6	Canister
7	EOBD connector
8	Sparks
9	Transformers
10	High temperature warning
11	ECU warning

13	Temperature sensor
14	High pressure
15	Position potentiometer
16	Knock sensor
17	RPM sensor
18	Key
19	Lambda sensor
20	Fuel pump
21	Relays
27	Low level fuel
28	Battery

Table 5-1 Name of each components in figure 5-2

5.1.2 Circuit connection of the ECU

We do not know the code in the ECU, but with schematics provided by the lab supervisor from the company Fiat, the parts of ECU controls can be easily understood.

The ECU platform has two parts, the connector A in the left and the connector B in the right. The circuits of the two connectors shows in the figure 5-3 and the figure 5-4 separately.

From Figure 5-3, it is easily to see that without the car electric system supply, the ECU doesn't have any power protection when it is connected to the power stage. So, for this part, in order to ensure the safety of the circuit we should remounted the protect circuit. That is to say, the fuses and relays should be added in the circuit A for this test bench. And this circuit is connected with the connector A. So, the next important step is to rebuild the circuit of the figure 5-3.

Figure 5-3 Basic electric circuit of the connector A
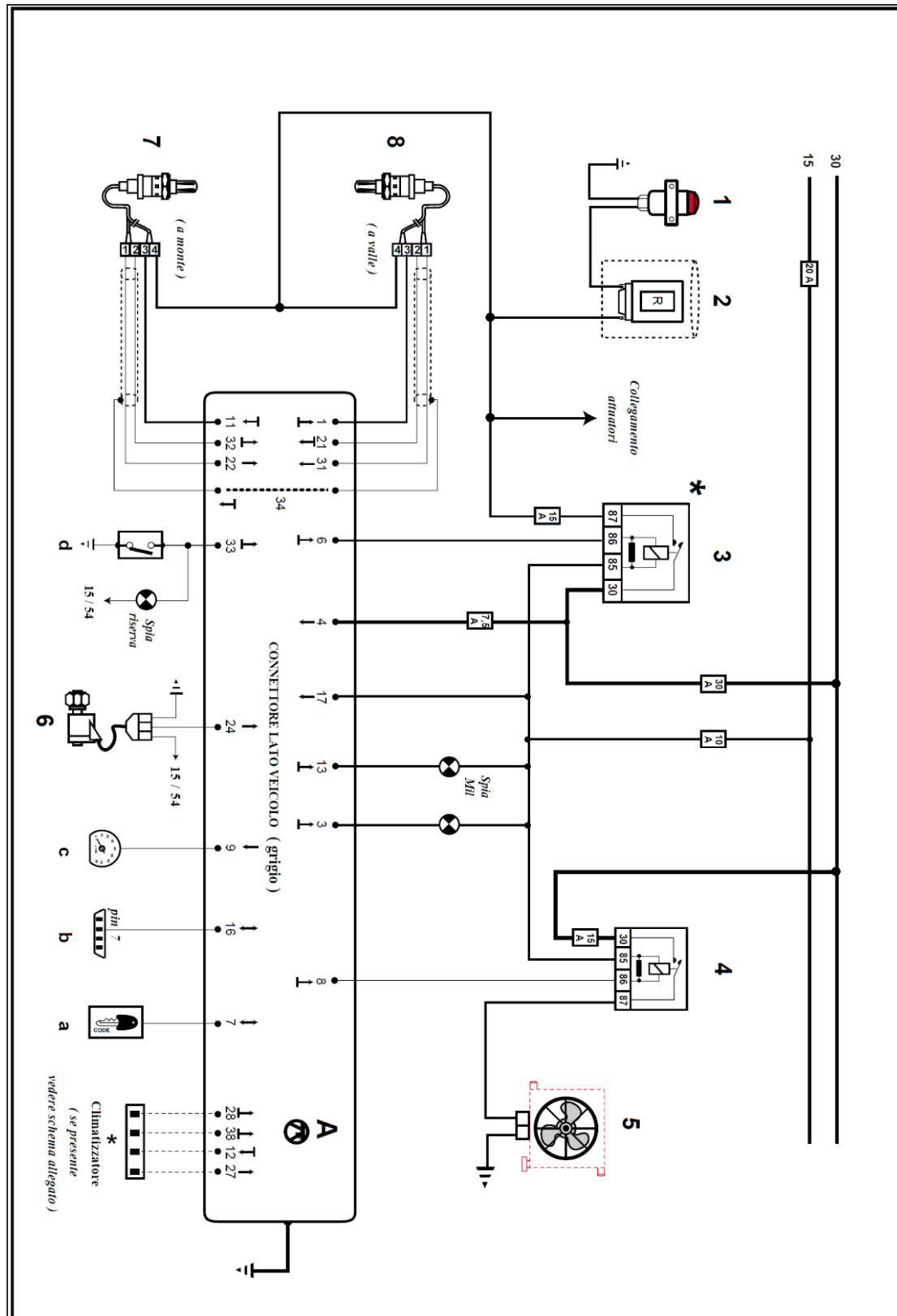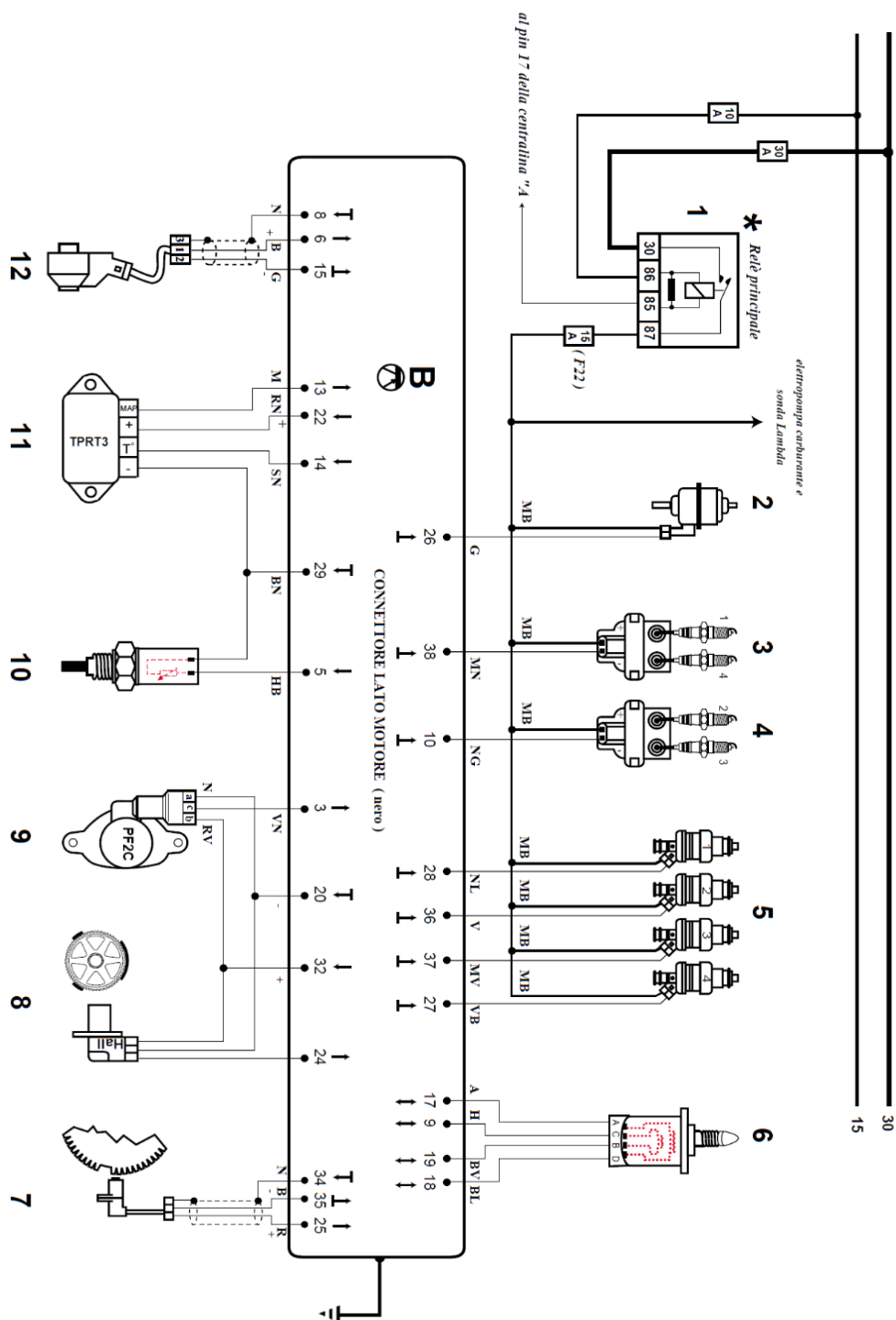
Figure 5-4 Basic electric circuit of the connector B

In the figure 5-3 and the figure 5-4:

- The wire 30 is the power supply which connect to the battery 12V.

- The wire 15 is the power supply under the key of the car.

In the table 5-2, shows the introduction of the components in the figure 5-3.

The number of the components	Name of the components
1	Inertial switch
2	Fuel pump
3	Main relay No.3
4	Relay No.4
5	Cooling fun
6	Speed sensor
7	Upstream λ sensor
8	Downstream λ sensor
A	The connector A in ECU
a	Key code
b	Diagnostic socket
c	Tachometer
d	Fuel level switch
*	Air conditioning

Table 5-2 Components in the figure 5-3

In the table 5-2, shows the introduction of the components in the figure 5-3

The number of the components	Name of the components
1	Mian relay No.3
2	Canister
3	Ignition coil of cylinder 1-4
4	Ignition coil of cylinder 2-3
5	Injectors
6	RPM sensor
7	Phase sensor
8	Accelerator potentiometer
10	Temperature sensor
11	Temperature /absolute pressure sensor
12	Knock sensor
B	The connector B in ECU

Table 5-3 Components in the figure 5-4

5.1.3 Connector remodelling

Figure 5-5 shows the pin number of the connector A and the connector B when face to the bottom of the two connectors.
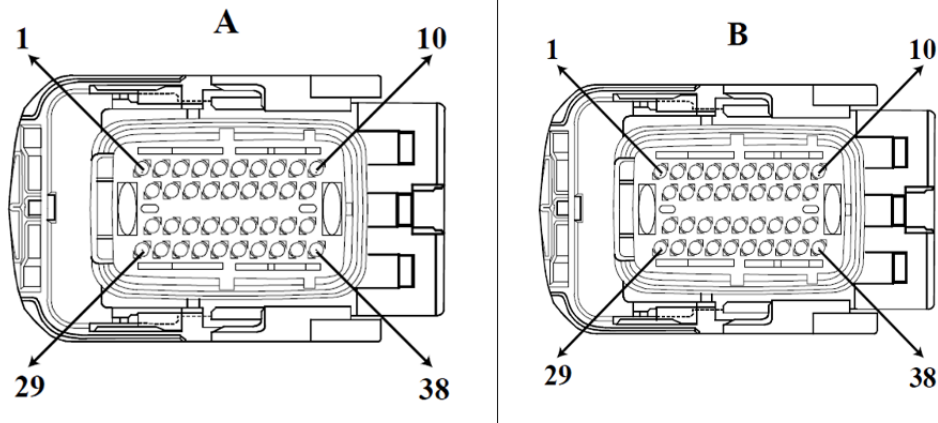
Figure 5-5 Pin of the A, B connector

Figure 5-6 shows the pin number in the ECU part.
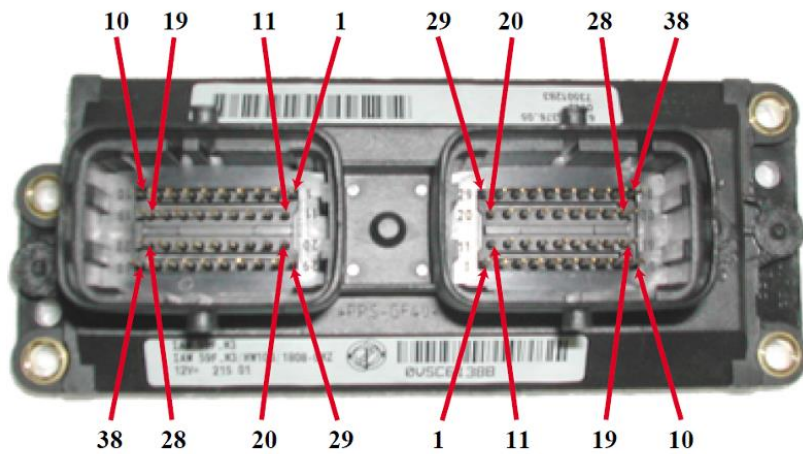
Figure 5-6 Pin in ECU part

From the figure 5-5 and the figure 5-6, it is not difficult to see that, the number the pin in the ECU part are inversed from the connector A and B part. The left part of the ECU connected to the connector A, and the right part is connected to the connector B.

Since in the ECU part, we only have the pin on it. We can not connect them to the circuit directly, and connector A and connector B can convert the pin to the wires. But there is a big problem for us of the connector part: the connector which is going to be used in this thesis doesn't have all the pins that we need. So, the new connector should be re-modelling by hands. Figure 5-7 shows the connector A after remodelling, all the pins have been fixed with wires. Then all the wires have been coded in order to make them easier to distinguish. And simplify connection work in the future.
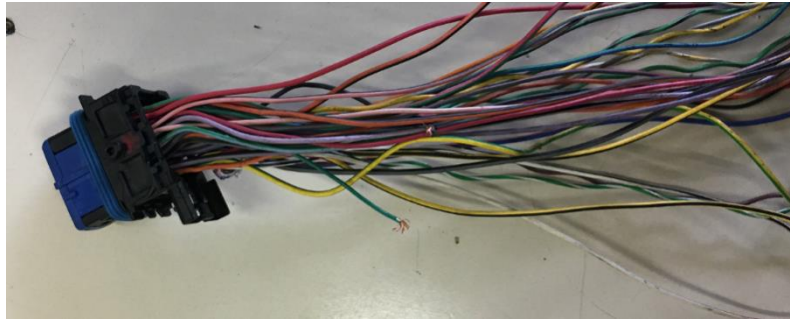
Figure 5-7 Connector A after remodelling

The table 5-2 shows the pins that are going to be used and connected.

Out of the original intention of this project, this engine test bench is used only for the didactic. So, some of the components in the figure 5-3 are not needed. Hence Not all the pins will be used in the connector A, the pins in the connector A will be used are the pin: 3, 4, 6, 8, 11, 13, 16, 17, 22, 24, 32, 33, 34. In the table 5-3 introduces the pins connection of the connector A.

The pin number in the connector A	The connection of the pin
Pin 3	The common node of the relay No.3 and No.4
Pin4	The fuse F18 then to the power supply
Pin 6	Pin 86 of the main relay No.3
Pin 8	Pin 86 of the relay No.4
Pin 11, 22, 32, 34	Upstream of the λ sensor
Pin 13	Voltage supply under the key
Pin 16	Voltage supply under the key
Pin 17	Voltage supply under the key
Pin 24	RPM sensor
Pin 33	Fuel level switch and the led

Table 5-4 Connection of the connector A

5.2 Protection circuit

From the figure 5-3 and the figure 5-4, the connection of sensors and actuators are easy for us politecnico students: just need to connect the same pin number together. And in the chapter 4.2 and the chapter 4.3, the pins of each sensors and actuators were already introduced with the diagrams, so the only difficult point is how to add the relays and the fuses into the circuit protect.

The preparation of the protection circuit:

- The fuses reparation

- The relays reparation

- The common nodes reparation

5.2.1 Fuses reparation

As the schematics showed in the figure 5-3 and figure 5-4, there are 5 fuses need to be mounted in the circuit. As the figure 5-3 required, the table 5-2 shows the value of the required fuses and the final chose of fuses value.

The number of the fuse	Required value	The value used	The color of the fuse
F11	15A	15A	Blue
F16	10A	10A	Red
F18	7.5A	10A	Red
F20	15A	15A	Yellow
F33	30A	30A	Green

Table 5-5 Fuses value and the colour in the protecion circuit

The wire of the same fuse base should be changed to the same thickness in order to bear the same current, while the wire of the different fuses should be changed to the different thickness in order to bear the different currents. The final wire dimension in the fuse base shows in table 5-3.

			F22		F11
M		B	B		M
M		B	B		M
F16		F33		F20	F18
T	T	B	M	B	T
T	T	B	M	B	T

Table 5-6 Wires thickness of the fuse base

In the table 5-3, the T, M, B means the thickness of the connected wires:

- The small dimension wire uses 'T' to express.

- The medium dimension wire uses 'M' to express.

- The large dimension wire uses 'B' to express.
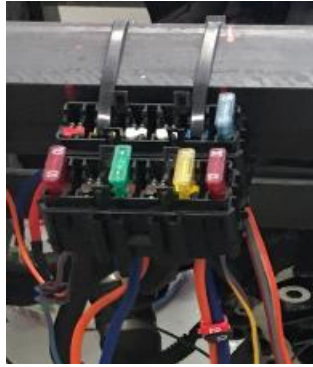
Figure 5-8 Final fuse base and fuses

The final fuse base and the fuses shows in the figure 5-8.

5.2.2 Relays reparation

There are three relays in the schematics in Figure 5-3 and Figure 5-4. But from the comparation of them, we can easily to understand that the relay No. 3 and relay No.1 is the same one which means the principle relay. Hence, in the control circuit, there are only two relays, the relay NO.1 is the principle relay, the rated current of this relay is 30A. The second relay is the relay No.4 and it's rated current is 20A.

There is always a relay box in the car. So, at the first we decided to use the relay box in the test bench. We get a relay box which removed from a car. The figure 5-9 shows the photo of the rely box. The pins conduction of the board are checked with the multimeter, the conduction of the pins shows in the Figure 6-7. The same letters mean the pins are conducted.
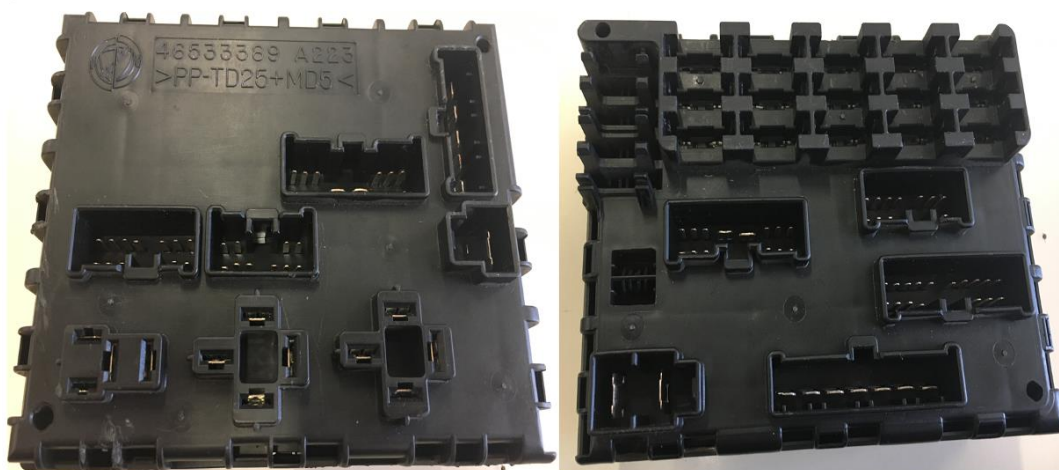
Figure 5-9 Board fixed in the box of relays
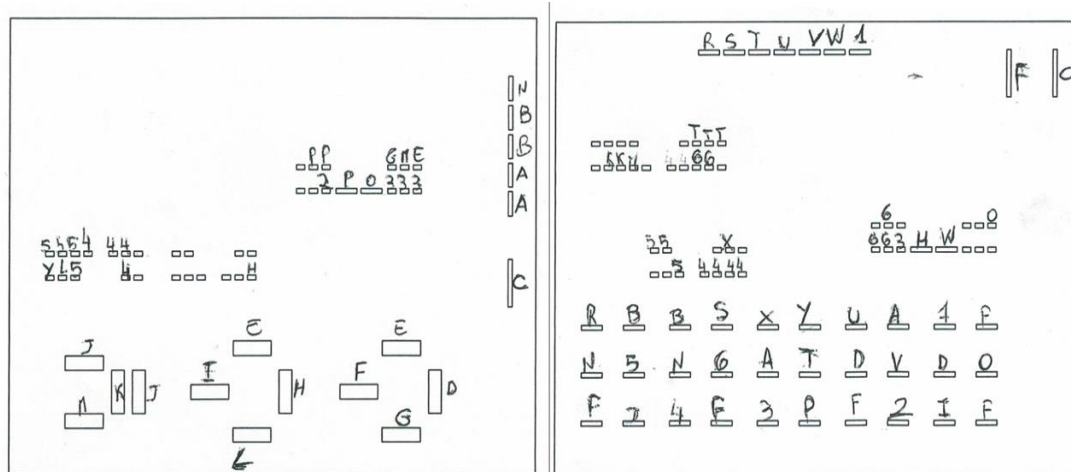
Figure 5-10 Pin conduction of the board in the box of relay

From the figure 5-10 the pins conduction status can easily to see. After the discussion with the lab supervisor, this board is not satisfied with the requirements. Then we decided to use the separately relays. One relay's rated current is 30A, the other rated current is 20A.

The figure 5-11 show the pin diagram of the relay No.3 which rated current is 30A.
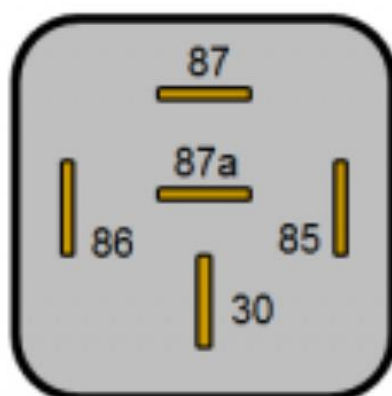
Figure 5-11 Pin number of the relay No.3

The figure 5-12 show the pin diagram of the relay No.4 which rated current is 20A. We can see that the relay No.4 is different from relay No.3 that only has 4 pins.

Figure 5-12 Pin number of the relay No.4

The base of the relays also needs to be built. The bases are tied up with the cable tie. The final relay base shows in the Figure 6-8.
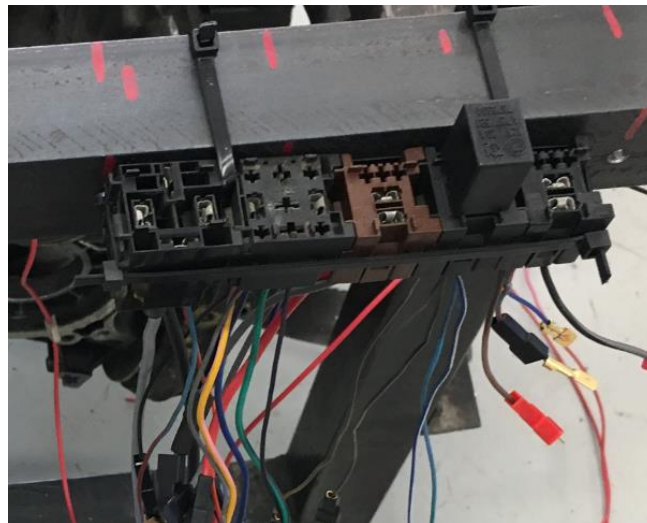
Figure 5-13 Final relay base tied in the test bench

5.2.3 Common nodes preparation

From the figure 5-3, it is easy to see that there are two nodes that have lots of wires in parallel. One is between the pin 3, 13, 17 and the power supply under the key (named it node 1). The other is between the lambda sensor, the relay pin 87, spark and injectors (named node 2). And in order to make the protection circuit looks beautiful and in order. Making two common nodes is a one good way to realize that purpose. Furthermore, there are two more nodes need to be created. One is for the power supply and the other is for the power supply under the key. The figure 5-14, figure 5-15 and the figure 5-16 shows the four common nodes separately.
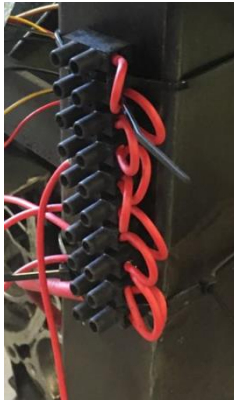
Figure 5-14 Common node of the power supply(12V)

Figure 5-15 Common node 2(left) and common node 1(right)

Figure 5-16 Common node under the key

5.3 Power supply and the indicating circuit

5.3.1 Design circuit

In order to design the power supply circuit, the two levels power supply must be achived at first. As the figure 5-3 and 5-4 shows, the wire 30 and the wire 15 must be complied due to the design. The wire 30 is directly connected to the positive of the battery, and the wire 15 get power only when the key conducted. Then the second requirement is that add the indicate lamp to show the work condition of the engine. The supply indicate

lamp shows whether have voltage under the key. The battery indicate lamp shows whether have the voltage supply to the circuit. And the oil indicate lamp the oil level.

The figure 5-17 shows the final designed power supply and indicating circuit of the engine test bench.
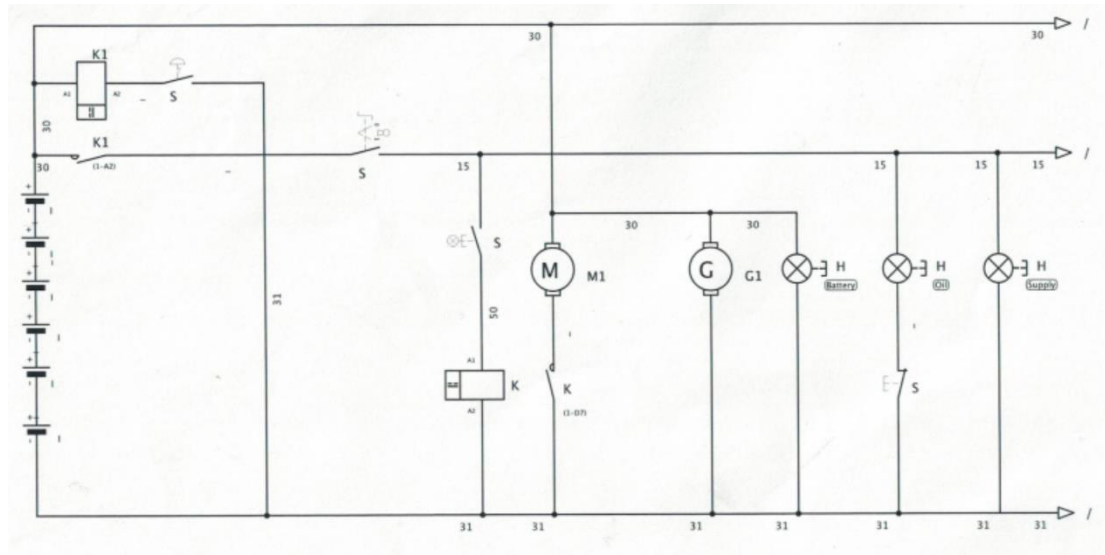
Figure 5-17 Indicating circuit

An electromagnetic relay K is used in the start circuit for the reason of safety. When the start button pushes down, the motor and the generator power on, and the lamp of battery the oil indicate lamp and the power supply indicate lamp all turn on, when the emergency push button pushes down, all the circuit doesn't work anymore. The emergency button is necessary, when some emergency situations occur, we just need to push the emergency button down and the engine will stop working.

From the circuit of the figure 5-17, the control panel can be built from the circuit. The figure 5-18 shows the final control panel of the project. It shows names of the lamps and the buttons.

In this thesis, the control panel has 5 lamps to show the working condition of the engine:

- The battery indicate lamp
- The oil indicate lamp
- The error in the ECU error indicate lamp
- The engine generator indicate lamp
- The over-heating indicate lamp

The control panel has 1 button to start the engine.

The control panel has the key like the car.

The control panel has the emergency button to stop the engine when emergency occurs.

Figure 5-18 Control panel

After designed the power supply and the indicating circuit, the circuit has been mounted behind the control panel which the Figure 6-14 shows the wire connection.
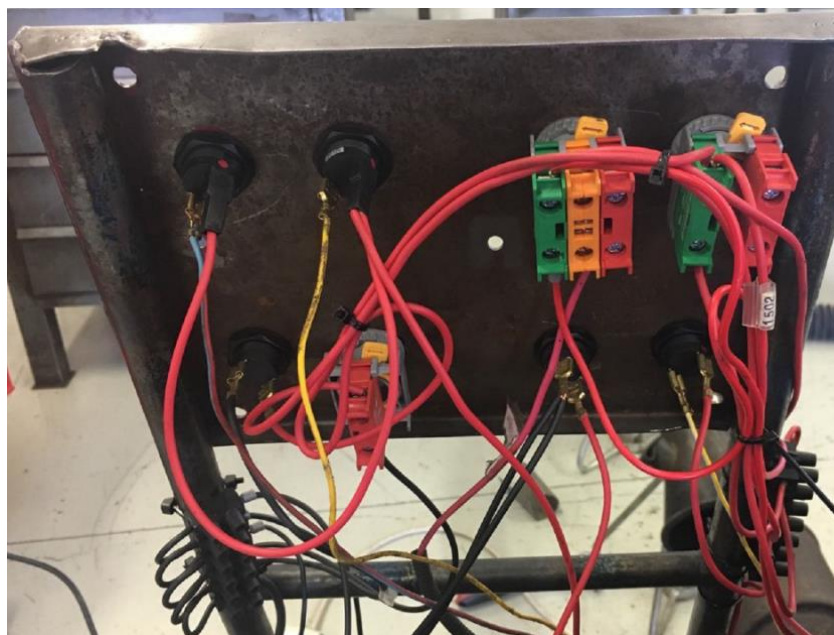
Figure 5-19 Wire connection of the indicating circuit

(the circuit behind the control panel)

The figure 5-20 shows the test bench after connected all the electric circuit.
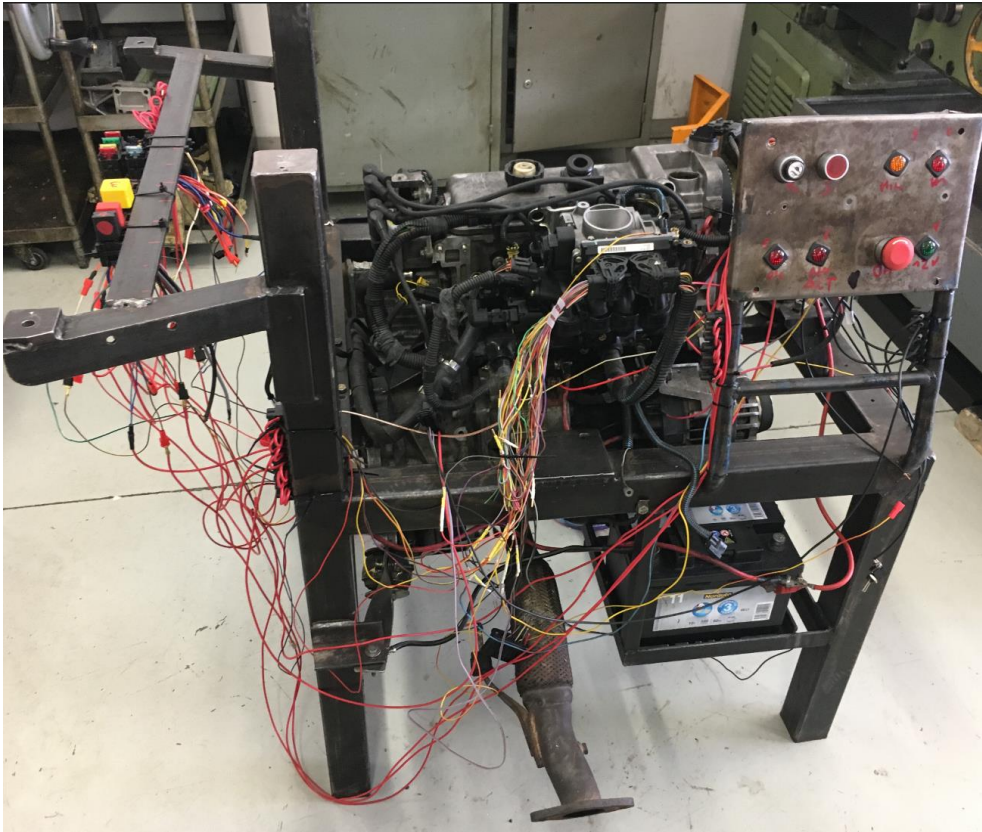
Figure 5-20 Engine test bench after the electric circuit connection

Chapter6 Auxiliary systems

Before running the engine, checking the leakage of the connection in the engine is necessary. In this chapter, the process of the checking is going to be introduced. In order to check the leakage, at the first, we used the air pressure, secondly, we injected the coolant oil in the engine.

6.1 Check leakage with air pressure

In order to check the leakage with the air pressure. At first, use the pipe connect the air pressure generator machine with the air pressure gun. Then connect the air pressure gun to the engine generator. We just need to start the air pressure generater and observe and listen whether it has the gas leakage. The figure 6-1 shows the air pressure gun connect to the engine generator and the figure 6-2 shows the photo of air pressure generator.

Figure 6-1 Air pressure gun connects to the engine generator

Figure 6-2 Air pressure generator

There is no obvious leakage through using the air pressure gun.

6.2 Inject the coolant oil

After using the air pressure gun, we didn't see any obviously leakage of the engine. So, we decided to do a further checking. We injected the coolant oil in the engine. Before injecting the oil in the engine, all the tubes in the engine should be locked with the tube locks. The figure 6-3 show one tube lock which locks the tube.

Figure 6-3 Tube lock with the tube

After locking the tubes, two bottles of coolant oil were injected in the engine, the figure 6-4 shows the photo of the process of injection the coolant liquid. But after injecting the coolant oil for a while, the leakage occurs. Some tubes didn't lock well with the tube lock, we relocked them again. But the radiator has a lot of points leaking after injecting the coolant oil, this leaking situation shows in the figure 6-5.

Figure 6-4 Inject the coolant oil in the engine

Figure 6-5 Radiator leaking

For saving the money. At first, we tried to use the waterproof glue to repair it. But there are too many holes in the radiator and it can not be repaired just put the glue in the top of the small holes. So, a new radiator must be bought for the project. After changing the radiator, the leakage stops.

6.3 Gasoline tank fabrication

The engine Fiat Punto 1.2 8V is a gasoline engine, the gasoline is the fuel of the engine. Before trying to make the engine runs, the fuel and the fuel tank should be prepared. The fuel is the gasoline 97# which must be bought in the fuel station. Since there is not a suitable fuel tank for the test bench. A fuel tank made by hand is necessary for this project.

Searched all the container in the lab, the container of the soap to clean the hand is the most suitable one to put the gasoline inside. The figure 6-6 shows the photo of the container of soap.

Figure 6-6 Soap container

But as the figure 6-6 shows, the container is too deep for the pump that the pump can not touch the bottom of the container. And for this reason, the gasoline at the bottom of the container can not be used. Therefore, the top part of the container is cut off by the saw and then the height of the container is suitable for the pump. The figure 6-7 shows the final tank can be used in the project.

Figure 6-7 Final tank used in the project

After finishing the three steps before, the engine tried to run. But the pressure of the gasoline is too much stress and the engine can not work in a normal working condition. So, a gasoline filter is fixed after the tank. Then the engine runs.

Chapter7 Data acquisition strategy

Getting the data from the engine is the aim of the project, so the data acquisition is an important step of the test bench. In this chapter the data acquisition strategy is going to be introduced. In this project, the data acquisition is performed by two sorts of diagnosis software (embedded systems), which will be explained in the following chapters. A comparison between them will be provided at the end of this chapter.

7.1 Bosch Diagnostics

7.1.1 Introduction of the Bosch Diagnostics

The Bosch Diagnostic is a tool that can scan the ECU of a car and gives information about the working condition of the car, it can give the information of the car's health state of all the components.

The purpose of the Bosch is saving money and saving time in trouble shooting and repairs. The Bosch board used in the thesis is the model: KTS525. The figure 7-1 shows the photo Bosch Car Scanner used in the thesis. It has the following features:

- As with the well-known modules in the KTS series, all the present and future vehicles can be quickly and reliably diagnosed using the KTS 525

- Wireless, bluetooth connection

- Software controlled by ESI (tronic)

- It can be connected to all the current PC through the USB interface

- It can be easily connected to a vehicle using the OBD connector

Figure 7-1 Bosch Car (ECU) Scanner

The figure 7-2 shows the software interface of the Bosch diagnostic in the PC.
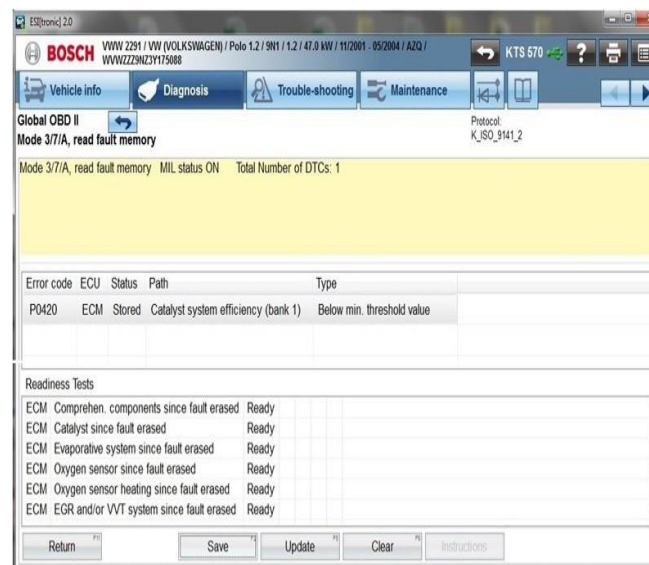
Figure 7-2 Interface of the ESI （tronic）

7.1.2 An example of the BOSCH data acquisition

We can select the parameters that we want to analyse with the Bosch diagnostics. The figure 7-3 and the figure 7-4 present an example of a good working condition engine from a car of Fiat Punto which belongs to one of the tutors in the Filos.
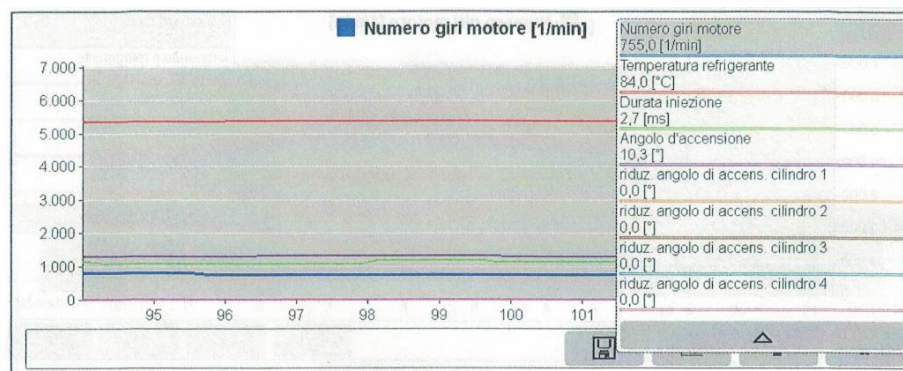
Figure 7-3 Lables of the testing lines in the test

Before starting the test, the software of the ESI will ask the customers to select the tests which they want to test. The figure 7-3 shows the tables of the testing lines in the test. Then the figure 7-4 shows the test result curves.
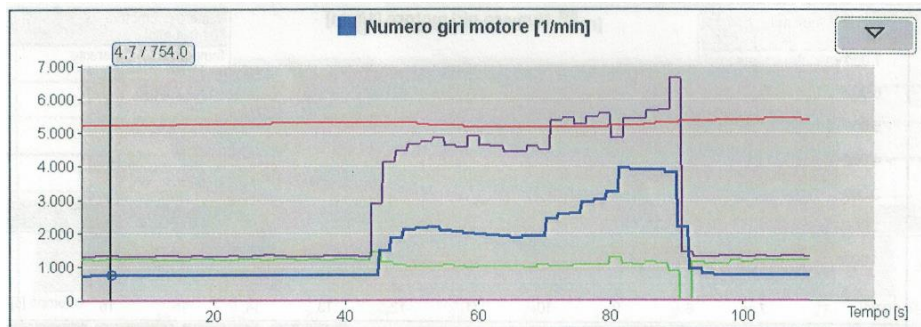
Figure 7-4 The relation between the throttle angle, coolant temperature, the RPM, the ignition time and the inition angle

The tabel 7-1 shows the name of each lines in the figure 7-3 and the figure 7-4.

Color of the curve	Name of the curve
Red	Coolant temperature
Purple	Throttle angle
Blue	RPM
Green	Ignition time
Light purple	Retarding ignition timing

Table 7-1 Name of the curves in the figure 7-3 and figure 7-4

From the figure 7-3 and the figure 7-4, it is easy to see that the relationship of the throttle angle, coolant temperature, the RPM, the ignition time and the ignition angle:

- The throttle angle is the only parameter changed, and in the car, it changes with the pedal.

- The RPM changes with the throttle angle changing. The more throttle angle is, the fast of the engine speed is. When the throttle angle decreases, the engine speed decreases too.

- As we said before, the more engine speed is, the more spark-advance the engine needs, the ignition time is the green curve in the figure 7-4. When the engine speed increases, the ignition time increases before the engine speed increasing, then decreases with the engine speed goes down, vice versa.

- The curve of the light purple is always stay in 0, that is to say there is no retarding ignition time in this process.

- The temperature of the coolant doesn't change so much in this attempt.

From the example of the Bosch diagnostic, we can see that a disadvantage of it. Sometimes the engine speed can not flow the change of the throttle angle, that because there is always a delay in the figure of the Bosch reflect. When there is a fast changing, the curve can not print it on the screen and then jump to the next data.

Since the curves of the Bosch diagnostic can not give the exact information from the diagrams, and the data only can be stored as graphs, we sought it is not a flexible way

in this project, since we need to analyse these data. So, the next diagnostic is going to be introduced in the chapter 7.2.

7.2 Multiecuscan Diagnostics

The Multiecuscan Diagnostics is another diagnostics tool which can give us the information of the state of the components that ECU controls. It is a diagnostic way like the Bosch. But the results of the data can be saved as the numerical or the graphs as the users want. The software can download from the web multiecuscan official web. The website to download the software is: https://www.multiecuscan.net/. The figure 7-5 shows the interface of the Multiecuscan diagnostic on the PC part. The software download is obviously easy for everyone, but the difficult part is how to make the connection between the PC and the European On Board Diagnostic (EOBD). The figure 7-6 shows, the pin of the EOBD connection.
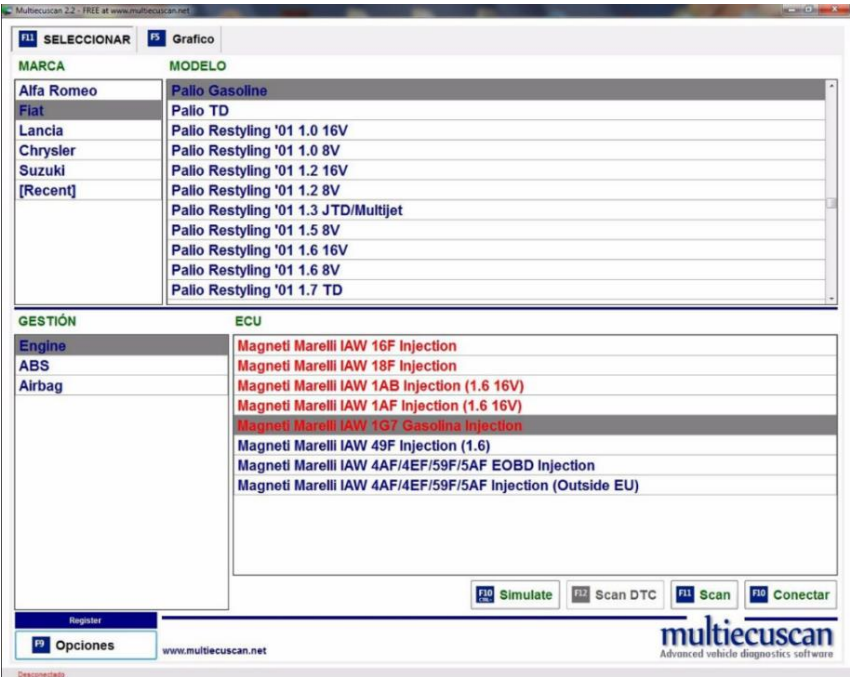
Figure 7-5 Software of the multiecuscan diagnostic
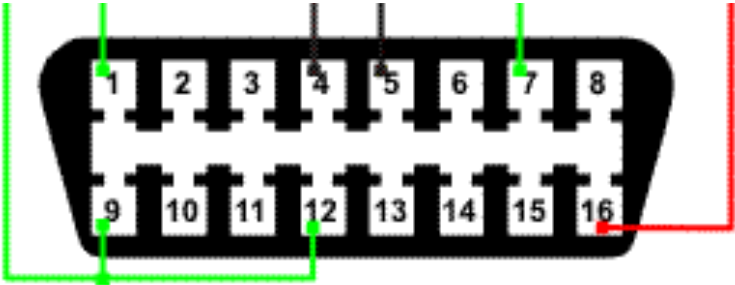
Figure 7-6 Male port connecte to vehicle

The table 7-2 shows the pin connection of the EOBD:

Pin number	The connection of the pin
1	Make / Model specific
2	SAE J1850-PWM POS (+) or SAE J1850-VPW POS (+)
3	Make / Model specific
4	Chassis Ground (all protocols)
5	Signal Ground (all protocols)
6	ISO15765-4 Can-Bus high
7	ISO9141-2 K-line or ISO14230-4 KWP 2000 K-line
8	Make / Model specific
9	Make / Model specific
10	SAE J1850-PWM NEG (-)
11	Make / Model specific
12	Make / Model specific
13	Make / Model specific
14	ISO15765-4 Can-Bus Low
15	ISO9141-2 Line or ISO14230-4 KWP2000 L-line
16	+12V (always on) (all protocols)

Table 7-2 EOBD pin connection

In order to make the EOBD connector of the engine test bench in this project, the pin No.4, pin No.5, pin No.7 and the pin No.16 are the 4 pins should be connected to the ECU.

The table 7-3 shows the relation between the EOBD male part with the engine part.

Pin number in the male port and the wires' colour	The ECU part of the wire number
Pin 4 (black)	Negtive of the battery
Pin 5 (purple)	Signal ground
Pin 7 (grey)	Pin 16 of the ECU
Pin 14 (red)	Positive of the battery

Table 7-3 Relation between the EOBD male part with the engine part

After the connector connecting, the software can get the signals from the connectors and then it can store the data obtained from the ECU. As we mentioned before, the data can be saved as the form of graphs and the form of the numerical. And one more analytical data will also be saved as the txt form. The suffix of the form of numerical is .csv. this form of data can be seen in excel, then it can easily be manipulated by Matlab. So, the numerical form is the data that we are going to use in this project.

Chapter8 Running the engine

From chapter 4, the engine was ready prepared. Chapter 5 the electronic part includes the protection circuit and the indicating circuit were ready. Then the last checking before running was done in the Chapter 6, and the way of the data collection was also chosen in the Chapter 7. So, the next step of the project is running the engine and to see whether it has some problems then solve them.

The right steps to start the engine is:

1. Putting the emergency button in the working state.
2. Turning the key to the 2nd position of the key. The figure 8-1 show the key position of the project.
3. Press the starting button

Figure 8-1 Engine key position

The right steps to stop the engine is:

1. Turning the key to the stop position '0'.
2. Push the emergency button to the emergency state.

8.1 The first attempt to run the engine

The first attempt to run the engine is absolutely ended in failure since the project is not an easy one. After we finished doing all the steps for starting the engine, there is nothing reaction of the engine. The data collected from the multiecuscan shows in the figure 8-2.

Time	Lambda 1 signal (Pre-Cat.)	Lambda sensor 1 integrator	Lambda 1 status (Pre-Cat.)	Lambda 1 diagnosis (Pre-Cat.)	Lambda 1	Engine sta	ECU Programmed	Engine status	Vehicle status
sec	V	%							
0,00	0,0000	10,000	Open Loop	Bottom Limit	OK	Allowed	Not Programmed	Stalled	Standstill
1,30	0,0000	10,000	Open Loop	Bottom Limit	OK	Allowed	Not Programmed	Stalled	Standstill
2,60	0,0000	10,000	Open Loop	Bottom Limit	OK	Allowed	Not Programmed	Stalled	Standstill
3,89	0,0000	10,000	Open Loop	Bottom Limit	OK	Allowed	Not Programmed	Stalled	Standstill
5,18	0,3270	10,000	Open Loop	Bottom Limit	OK	Allowed	Not Programmed	Stalled	Standstill
6,48	0,2930	10,000	Open Loop	Bottom Limit	OK	Allowed	Not Programmed	Stalled	Standstill
7,77	0,3020	10,000	Open Loop	Bottom Limit	OK	Allowed	Not Programmed	Running	Standstill
9,08	0,3170	10,000	Open Loop	Bottom Limit	OK	Allowed	Not Programmed	Stalled	Standstill
10,38	0,2930	10,000	Open Loop	Bottom Limit	OK	Allowed	Not Programmed	Stalled	Standstill
11,67	0,2970	10,000	Open Loop	Bottom Limit	OK	Allowed	Not Programmed	Stalled	Standstill
12,96	0,0000	10,000	Open Loop	Bottom Limit	OK	Allowed	Not Programmed	Stalled	Standstill
14,26	0,0000	10,000	Open Loop	Bottom Limit	OK	Allowed	Not Programmed	Stalled	Standstill
15,56	0,0000	10,000	Open Loop	Bottom Limit	OK	Allowed	Not Programmed	Stalled	Standstill
16,85	0,0000	10,000	Open Loop	Bottom Limit	OK	Allowed	Not Programmed	Stalled	Standstill
18,15	0,0000	10,000	Open Loop	Bottom Limit	OK	Allowed	Not Programmed	Stalled	Standstill
19,45	0,0000	10,000	Open Loop	Bottom Limit	OK	Allowed	Not Programmed	Stalled	Standstill
20,75	0,0000	10,000	Open Loop	Bottom Limit	OK	Allowed	Not Programmed	Stalled	Standstill
22,04	0,0000	10,000	Open Loop	Bottom Limit	OK	Allowed	Not Programmed	Stalled	Standstill

Figure 8-2 The first attempt results from the multiecuscan

From the figure 8-2, the diagnostic result tells us that the ECU doesn't work at all.

In order to determine the problems. The following steps was done:

1. Check the mechanic part of the engine. Especially the sensors replacements.
2. Check the electrical part of the test bench. Especially the protection circuit.

After checking the two steps, there is nothing wrong with our job. So, we supposed that this is the problem of the ECU hack. Then the supervisor asked the help from an expert to hack the ECU again. Then we started to do the second attempt to run the engine.

8.2 The second attempt to run the engine

After changing the ECU of the engine, we did the second attempt to run the engine, but this time, an error occurred again.

In this attempt, the engine speed goes up by itself without the change of the throttle. Furthermore, the engine can not stop by locking the key of the engine and even push the emergency button down. The only way to stop the engine is pulling the transformers off. The figure 8-3 shows the second attempt running engine data from the multiecuscan.

In order to check the problem of the engine, we started the engine again, and tried to stop the engine in different ways. We get the two effective ways to stops the engine which are:

1. Pulling the transformer of the engine off
2. Unplug the main relay.

In view of the two transformers were already checked before the installation of the engine. We ascertain the error of the engine is caused by the main relay. Then a new main relay is changed in the protection circuit.

Time	Battery voltage	Engine speed	Engine temperature	Injection time	Throttle position	Throttle position	Idle actuator
sec	V	rpm	°C	ms	deg.	%	steps
0,00	122,000	0,0000	470,000	0,0000	0,0000	0,0000	1,150,000
1,15	122,000	0,0000	470,000	0,0000	0,0000	0,0000	1,150,000
2,30	122,000	0,0000	470,000	0,0000	0,0000	0,0000	1,150,000
3,46	122,000	0,0000	470,000	0,0000	0,0000	0,0000	1,150,000
4,63	122,000	0,0000	470,000	0,0000	0,0000	0,0000	1,150,000
5,78	122,000	0,0000	470,000	0,0000	0,0000	0,0000	1,150,000
6,94	122,000	0,0000	470,000	0,0000	0,0000	0,0000	1,150,000
8,10	122,000	0,0000	470,000	0,0000	0,0000	0,0000	1,150,000
9,24	122,000	0,0000	470,000	0,0000	0,0000	0,0000	1,150,000
10,40	122,000	0,0000	470,000	0,0000	0,0000	0,0000	1,150,000
11,56	122,000	0,0000	470,000	0,0000	0,0000	0,0000	1,150,000
12,71	96,000	0,0000	470,000	188,800	0,0000	0,0000	1,150,000
13,97	126,000	22,160,000	470,000	67,580	0,0000	0,0000	1,010,000
15,12	126,000	26,990,000	470,000	54,180	0,0000	0,0000	790,000
16,27	127,000	26,490,000	470,000	52,400	0,0000	0,0000	800,000
17,42	126,000	27,000,000	470,000	49,660	0,1000	0,0000	870,000
19,25	125,000	16,320,000	470,000	73,460	0,1000	0,0000	760,000
20,57	124,000	11,730,000	470,000	74,100	0,1000	0,0000	790,000

Figure 8-3 The second attempt result from the multiecuscan

8.3 The third attempt to run the engine

After solving the problems of the two attempts before, the third attempt is done, but this time the third problem occurs again. The diagnostic of the multiecuscan shows the problem of this attempt. The figure 8-3 shows the data which the multiecuscan gives us.

```
ECU ISO Code: 0D 07 13 80 7C
31/05/2018 14:39:40
CONNECTED TO:
Fiat Palio Restyling 2 '04 1.1 8V
Magneti Marelli IAW 4AF/4EF/59F/5AF EOBD Injection
-----------------------------------------------------------

ECU ISO code: 0D 07 13 80 7C
FIAT drawing number: 55181151
Hardware number: IAW59FHW305
Hardware version: 00
Software number: 18080YZ
Software version: 0000
Homologation number: 59FM5
ECU programming date: 11/29/2002

EXECUTING ACTUATOR...
Injector 1
COMPLETED


EXECUTING ACTUATOR...
Injector 2
COMPLETED


EXECUTING ACTUATOR...
Injector 3
COMPLETED


EXECUTING ACTUATOR...
Injector 4
COMPLETED


EXECUTING ADJUSTMENT...
Self-adaptation reset
FAILED TO EXECUTE
Incorrect conditions to run this test!

READING ERROR CODES:
1: P0230 - Fuel pump relay
ERROR DETAILS:
Fault status: Open circuit
Engine temperature: 23 °C
Engine speed: 0 rpm
Intake pressure: 960 mBar
Engine status: Off
Throttle position: 0 deg.
Spark advance: 0,0 deg.
```

Figure 8-4 The third diagnostic from the multiecuscan

The multiecuscan diagnostic gives the information that it is the problem of the pressure of the oil. So, a regulator is needed in the project and should be add it after the gasoline pump. The figure 8-5 shows the photo of the regulator of the oil pressure. And the figure 8-6 shows the photo that add the regulator after the gasoline pump.

Figure 8-5 Regulator of the oil pressure

Figure 8-6 Add the regulator after the gasoline pump

8.4 The fourth attempt to run the engine

After solving all the problems mentioned before, then the engine started, and began to run, and the RPM can go up we increased the throttle position. but the problem is that the engine can not keep the speed in smoothly. The speed of the engine always up and down, just like the engine stucks.

After checking all the engine, we occur that the pipe under the injector haven't be blocked. After blocking it, the engine runs successfully. Blocked the pipe shows in the figure 8-6.

Figure 8-7 Blocked pipe under the injector

Chapter9 Data processing

The engine runs sucessfully after the Chapter 8 descript. The data can be collected through the multiecuscan software and the EOBD which already introduced in Chapter 7. The next step is processing the data gets from the multiecuscan.

The multiecuscan can get three kinds of the data.

1. The numerical data. An example of the data shows in figure 9-1.
2. The graphic data. An example of the data shows in figure 9-2.
3. The analytic data. An example of the data shows in figure 9-3.

Time	Battery voltage	Engine speed	Engine temperature	Injection time	Throttle position	
sec	V	rpm	°C	ms	deg.	9
0,00	122,000	0,0000	470,000	0,0000	0,0000	
1,15	122,000	0,0000	470,000	0,0000	0,0000	
2,30	122,000	0,0000	470,000	0,0000	0,0000	
3,46	122,000	0,0000	470,000	0,0000	0,0000	
4,63	122,000	0,0000	470,000	0,0000	0,0000	
5,78	122,000	0,0000	470,000	0,0000	0,0000	
6,94	122,000	0,0000	470,000	0,0000	0,0000	
8,10	122,000	0,0000	470,000	0,0000	0,0000	
9,24	122,000	0,0000	470,000	0,0000	0,0000	
10,40	122,000	0,0000	470,000	0,0000	0,0000	
11,56	122,000	0,0000	470,000	0,0000	0,0000	
12,71	96,000	0,0000	470,000	188,800	0,0000	
13,97	126,000	22,160,000	470,000	67,580	0,0000	
15,12	126,000	26,990,000	470,000	54,180	0,0000	
16,27	127,000	26,490,000	470,000	52,400	0,0000	
17,42	126,000	27,000,000	470,000	49,660	0,1000	
19,25	125,000	16,320,000	470,000	73,460	0,1000	
20,57	124,000	11,730,000	470,000	74,100	0,1000	

Figure 9-1 A numerical data example gets from the multiecuscan
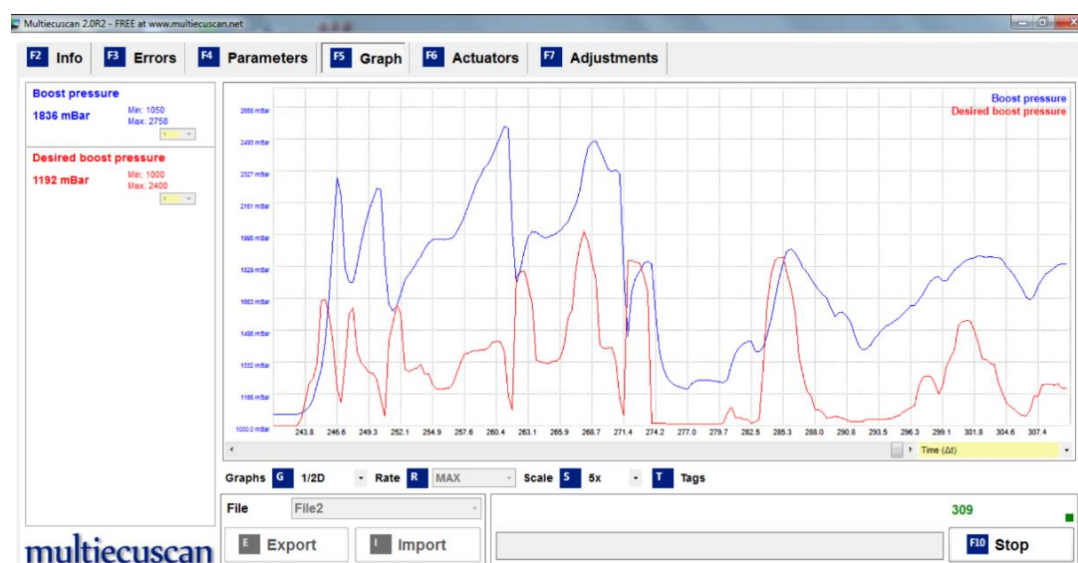

Figure 9-2 A graphic data example gets from the multiecuscan

```
ECU ISO Code: 0D 07 13 80 7C
01/06/2018 11:50:49
CONNECTED TO:
Fiat Palio Restyling 2 '04 1.1 8V
Magneti Marelli IAW 4AF/4EF/59F/5AF EOBD Injection
--------------------------------------------------------------

ECU ISO code: 0D 07 13 80 7C
FIAT drawing number: 55181151
Hardware number: IAW59FHW305
Hardware version: 00
Software number: 18080YZ
Software version: 0000
Homologation number: 59FM5
ECU programming date: 11/29/2002

READING ERROR CODES:
1: P0141 - Lambda 1 heater below catalyser
ERROR DETAILS:
Fault status: Open circuit
Engine temperature: 79 °C
Engine speed: 0 rpm
Intake pressure: 960 mBar
Engine status: Running
```

Figure 9-3 An analytic data gets from the multiecuscan

From the figure 9-1, the figure 9-2 and the figure 9-3, it is obviously that the graphic data and the analytic data do not need to be processed since it is easy to the relationship directly, but they are not flexible enough for the late data comparision, so the collected data in this thesis all saved as the numerical forms. Hence, the data processing after the experiments is necessary.

The numerical form data can be plotted through the Matlab. Through the Matlab we can get any graphic data that we want to compare with. An example data which is processed through the Matlab is showed in the figure 9-4. And the processed data will be used in the next chapter to analysis the data get from the test bench.
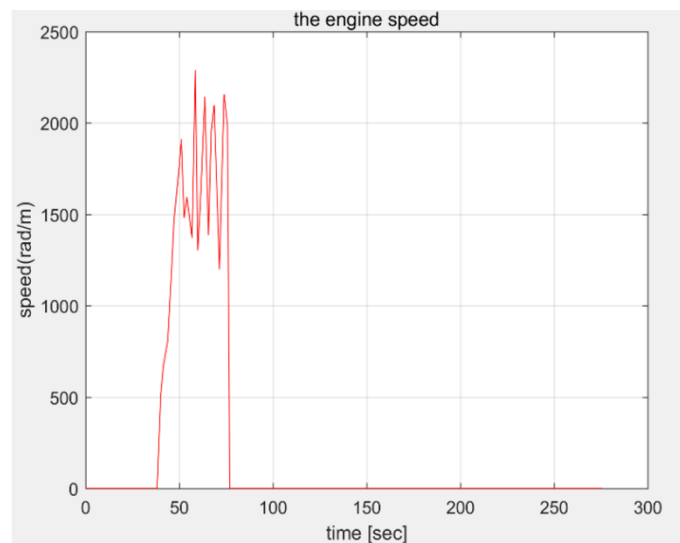

Figure 9-4 An example data processed throuh the matlab

Chapter10 The data analysis

After the chapter 9, we already know how to process the data get from the multiecuscan, in this chapter, the data is going to be analysed.

10.1 Data analysis of the engine speed

The engine speed is one of the parameters that we most concerned about. The figure 10-1 shows the comparison of the throttle angle, idle speed and the engine real speed in the experiment. It is easy to see that, the real engine speed keeps at the speed as the idle RPM when the throttle keeps at 0 rad, but it has a little unstable. The idle engine speed is about 1000 rad/s.
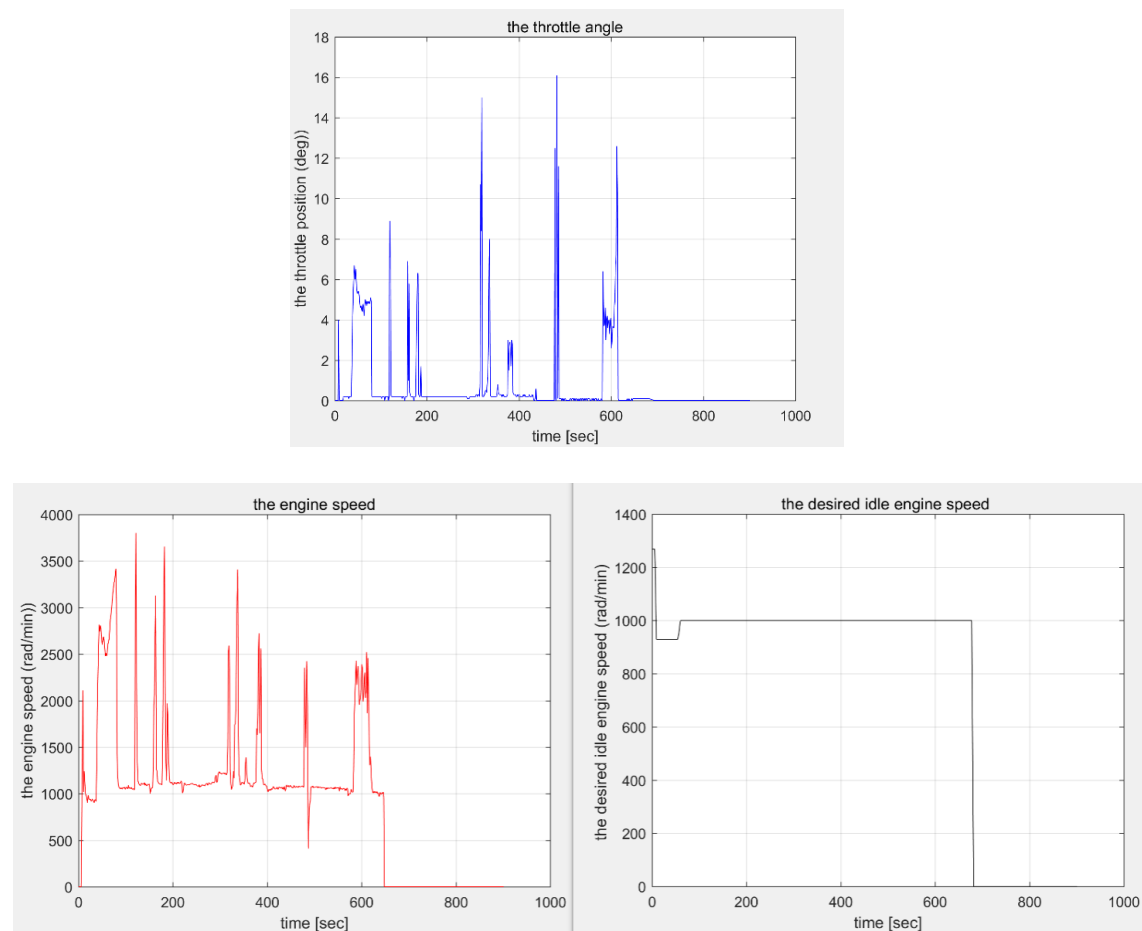

Figure 10-1 The comparasion the idle RPM and the real RPM

10.2 Data analysis of the knock sensor

After the engine running, we first measured the knock sensor signal of the engine. The figure 10-2 shows the processed data which collected through the multiecuscan of the knock sensor.
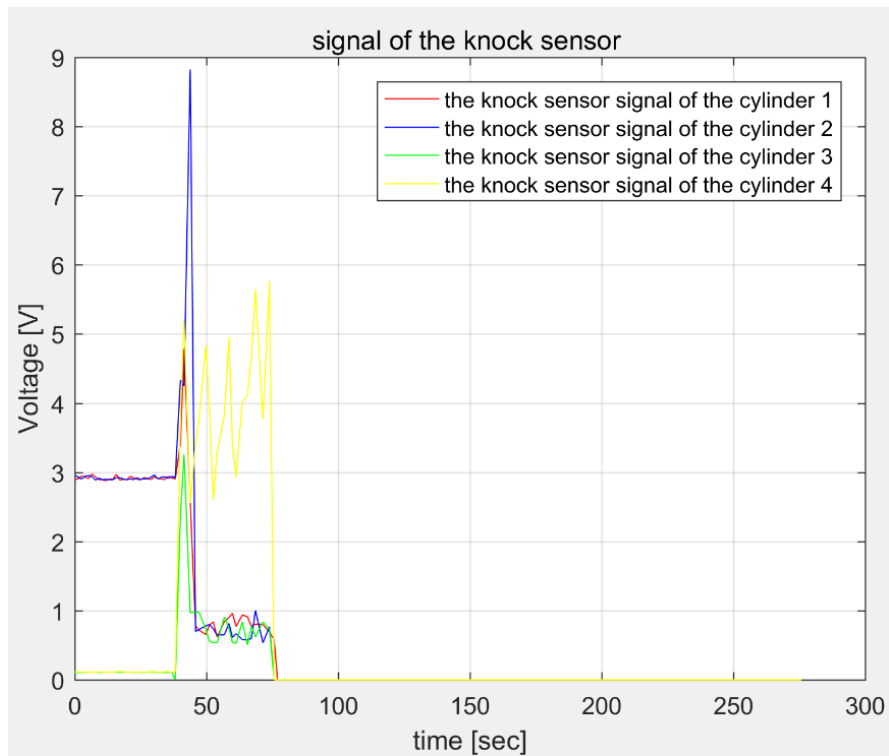
Figure 10-2 Signal of the knock sensor

The figure 10-3 show the relation between the knock senor signals with the spark advance time. As the knock sensor introduction, If the knock sensor sensed a ping, it will retard the ignition timing to protect the engine from this damaging pre-ignition. The black enlarges with the knock sensor sensed the knock of the engine.
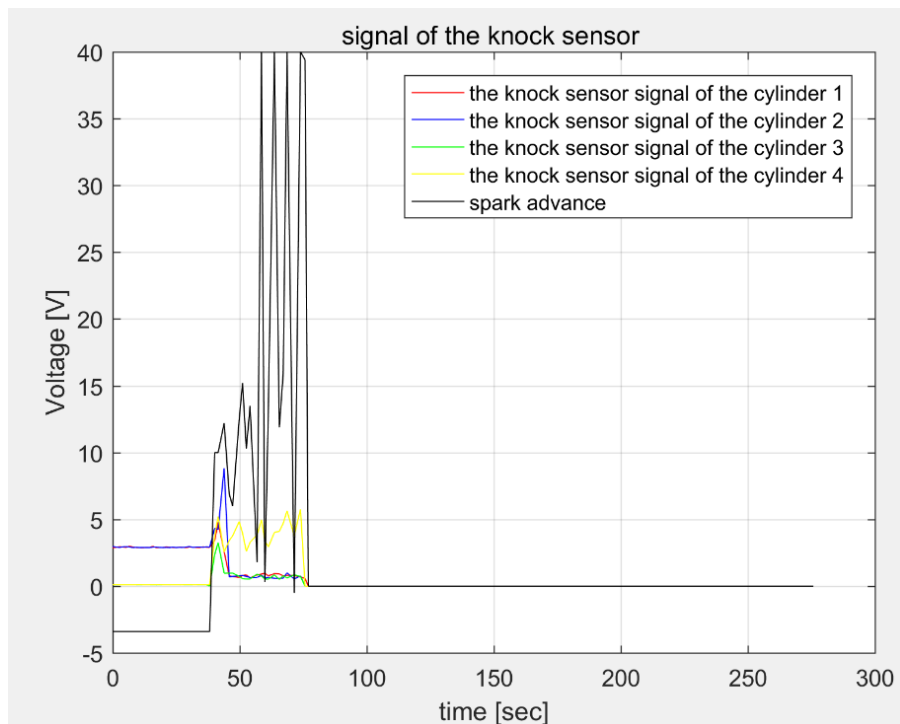

Figure 10-3 Relation between the knock senor signals with the spark advance time

10.3 Data analysis of the engine speed and spark advance

In this sub-chapter, the relation of the engine speed of the spark advance are going to be compared.

From the figure 10-4 and the figure 10-5 provide two diagrams of the comparison of the engine speed and the spark advance.
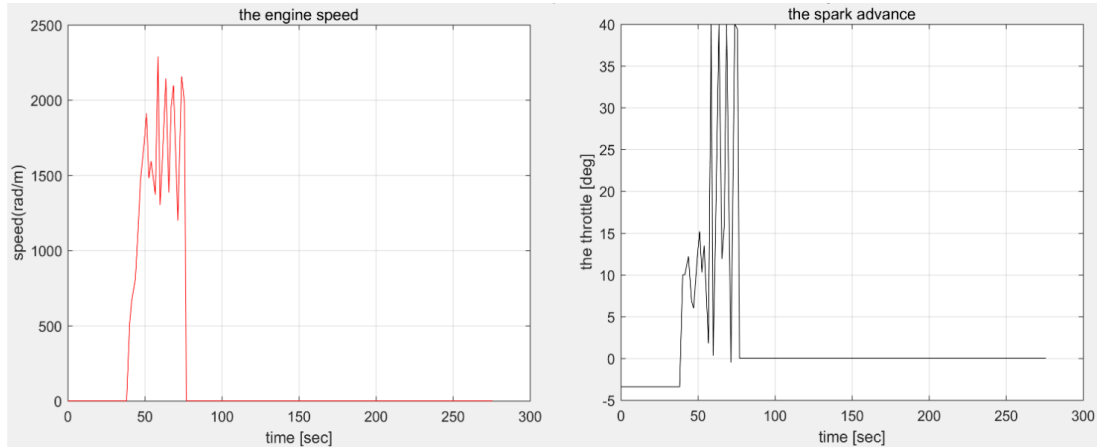

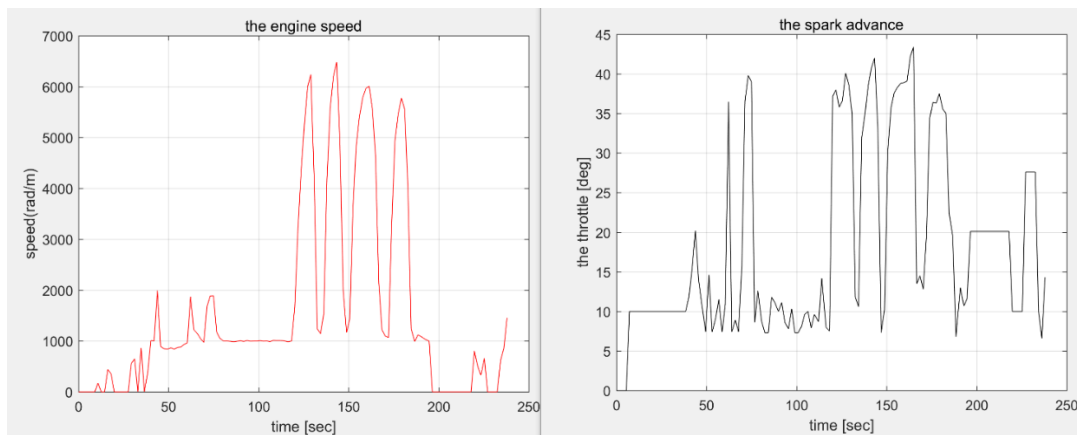*Figure 10-4 Engine speed and the spark advance 1*

Figure 10-5 Engine speed and the spark advance 2

From the figure 10-4 and figure 10-5, we can easily see that the shape of the engine speed and the shape of the spark advance are quite similar, so there must a relationship between the engine speed and the spark advance. As the introduction of the inject timing in the chapter 3.1.3.1. The more engine speed, the more spark advance is required. The two graphs all can verify this theory. The engine speed increases, the spark advance time is also enlarged at almost the same time.

10.4 Data analysis of the engine speed and coil charging time

The figure 10-6 shows the relation between the engine speed and the coil charging time.

When the coil is charging, the spark plug ignites. From the figure 10-6, the two coils charging time are almost the same. When the engine speed changes, the coil charging time changes at almost the same time.
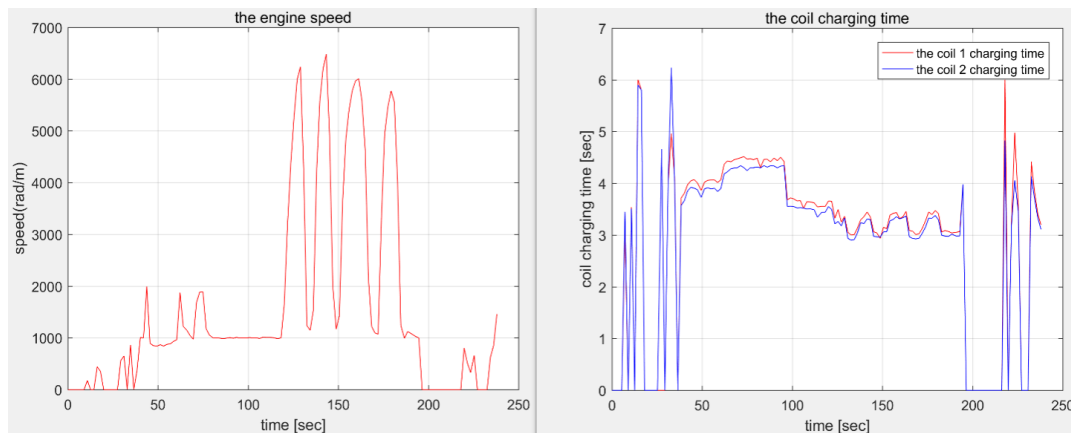

Figure 10-6 The relation between the engine speed and the coil charging time

10.5 Data analysis of the throttle angle and engine speed

The figure 10-7 shows the relation between the throttle angle and the engine speed.
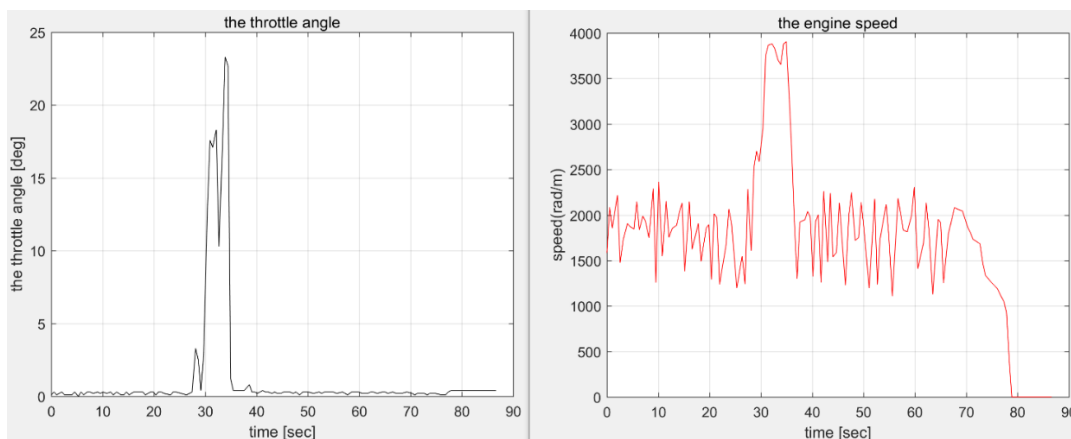

Figure 10-7 The relation between the throttle angle and the engine speed

From the figure 10-7, it is easily to see the relationship between the throttle angle and the engine speed. From the common sense, the throttle connects to the pedal of the car, and the car's pedal changes the speed of the car. From the figure 10-7. The basic knowledge also has been verified. When the throttle angle increases, the speed of the engine increases as well.

10.6 Data analysis of the step motor

The figure 10-8 shows the data of the engine speed and the step motor speed collected in the project.
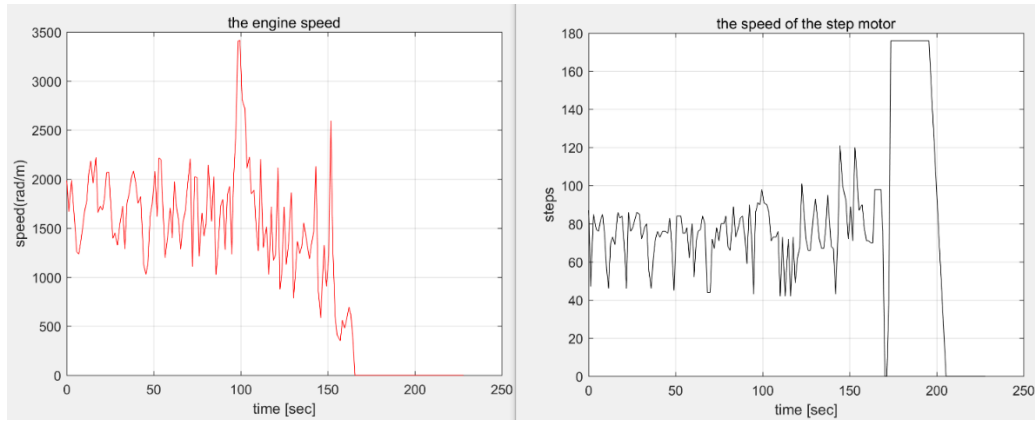
Figure 10-8 Engine speed and the step motor curve

From the figure 10-8, we can see that the speed of the step motor has the same trend with the engine speed, as the basic knowledge introduced in the chapter 2.2, the step motor will disengage when the engine speed is too fast. But in this experiment, the engine doesn't have so much speed, so the step motor doesn't disengage with the engine during this experiment.

10.7 The other information can be processed.

The multiecuscan can collect all the information that we want to analysis, then from the data processing, we can analyse the data in the way that we like. After the analysis the data from the engine, we can know all the parts of the engine working condition. The figure 10-9 and the figure 10-10 shows some examples of the data can be processed and analysed. The figure 10-9 temperature of the engine and the temperature of the air. And the figure 10-10 shows an example curve of the intake pressure of the engine which we got from the test bench.
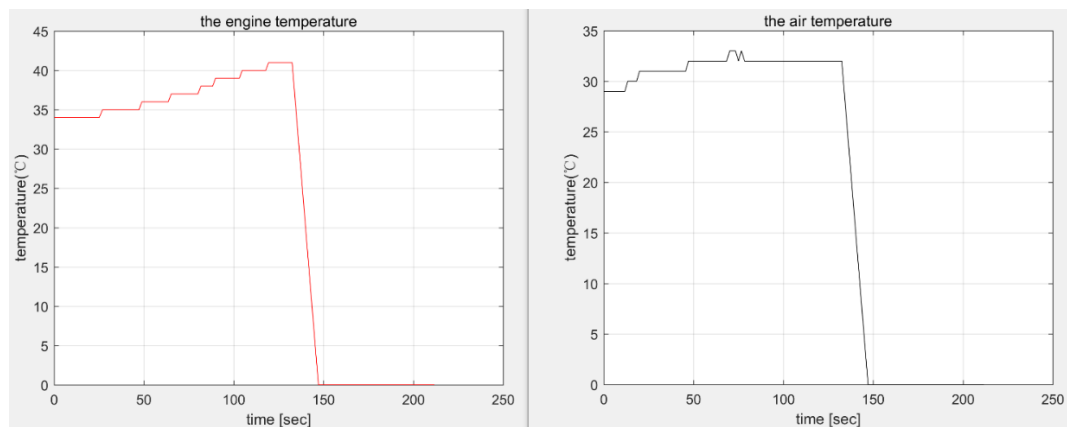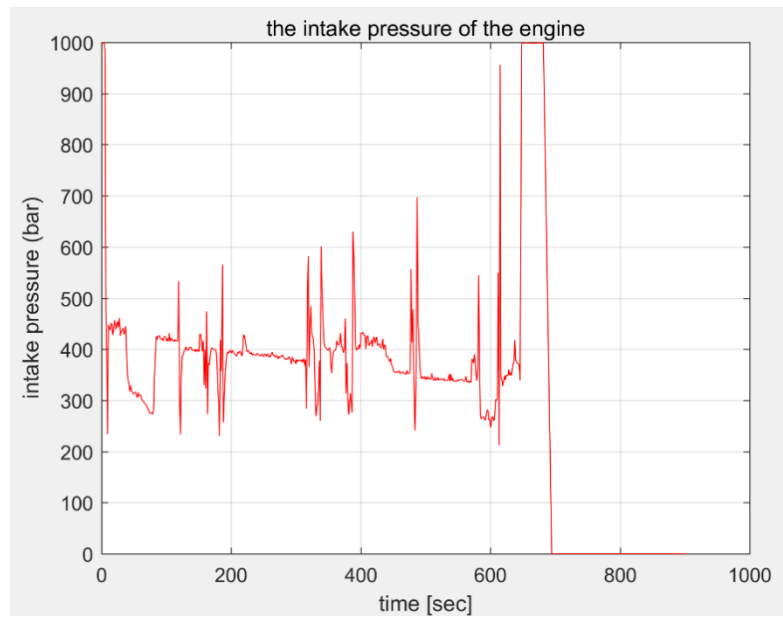

Figure 10-9 The temperature of the engine and the air

Figure 10-10 An example intake pressure got from the test bench

Chapter11 Conclusion

This thesis mainly introduces the procedures of building the didactic test bench for a car's engine. From the beginning, simulate the engine with the Arduino, check the re-assembling the mechanical part of engine then mounted the circuit of the engine control part and the indicating part. At last, the data collection, the data processing and the data analysis. The didactic engine test bench for a car's engine is completed successfully.

After analysing the data, we are sure that the engine of the test bench has a good working condition and it can be used in the class teaching in the Filos.

But in the limited time, there are many insufficients exist. And they can be improved in the future, for example:

1. The outlook of the engine can be improved, since the wires are sticking everywhere in the test bench. The wires should be covered with an insulating shell and then stick on the test bench, to avoid the short circuit and promised the safety during the didactic process.

2. Secondly, the ECU of the test bench is hacked by an expert, in the future, the students who is going to continually improve the test bench can write the code of the ECU himself. It will make the test bench more perfect.

And for me, this final project let me get a lot of knowledge about the car's engine, both from the theoretical and the practical. It must provide a lot of benefits for my future work and study. Of course, I will continually study the knowledge of the engine. Because from the thesis, it makes me interested at the engine of the car.

Appendix A:

A1 Simulation of the engine:

One of us works on the simulation of the engine. So, the students can understand the engine working principle from the experiment.

A1.1 ECU simulation

In order to simulate the engine, the ECU of the engine must be simulated at the first, the ECU controls the components work.

There are lots of boards can be used for the simulation of the ECU, but the Arduino is the board which we preferred to use. Arduino is an open source electronics platform based on easy to use hardware and software. It can read the input signal for example the input-light of the sensor, a finger on the button or even a message from the twitter then turn it into an output. The output of the Arduino can active the motor, turning on a LED, or publishing something online.

The advantages of the Arduino are:

- Low cost: Compare to the other microcontroller platforms the Arduino is inexpensive.

- Cross platform: Unlike a lot of microcontrollers are limitied to windows system. The Arduino can run on Windows, Macintosh OSX, and Linux operating systems.

- Simple and clear programming environment: It is simple for the beginners and even flexible for the advanced users to take the advantages as well.

- Open source and extensible software and hardware: The software is published as an open source tools which are available for extension by the experienced programmers. And the Arduino board are published under the Creative Commons License. So, the experienced circuit design can make their own module, extending it and improving it.

At first the Arduino Uno is chosen as the ECU of the simulation circuit. But in the following experiment, the processing speed and the resources of the Arduino Uno is not satisfied to our requirements.

Then the Arduino Mega 2560 is used in this project. The figure A1-1 shows the photo of the board of Arduino Mega 2560.
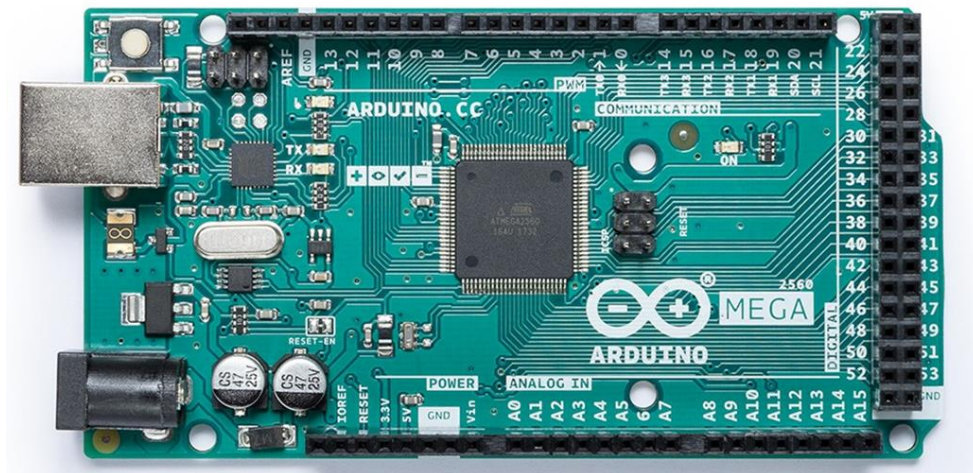
Figure A1- 1 Arduino Mega 2560

From the figure A1-1, and the hand book of the Arduino Mega 2560, we can know the basic parameters of it. The Arduino Mega 2560 has 54 digital input/output pins, 15 pins can be used as PWM outputs, 16 pins of analog inputs, 4 UARTs, one 16 MHz crystal oscillator, one power jack, one ICSP header, one USB connection, and one reset button. The Arduino Mega 2560 connect to a computer through a USB cable. And in order to get power on, an AC-to-DC adapter or a 5V battery is required. The figure A1-2 shows an example of the interface of the Arduino software.

Figure A1- 2 Interface of the Arduino software

A1.2 Actuators and sensors simulation

There are two main circuit to simulate the engine

1. The first circuit simulation simulates the injectors, ignition, the rod, the temperature sensors and the throttle of the engine

2. The second circuit simulation is mainly to introduce the running of the engine and the RPM sensor.

A1.2.1 The first simulation circuit

The first circuit simulated the engine injector, the spark ignition the temperature sensors and the moving of the throttle. The circuit diagram of the first simulation shows in figure A1-3. And the experimental circuit shows in the figure A1-4.
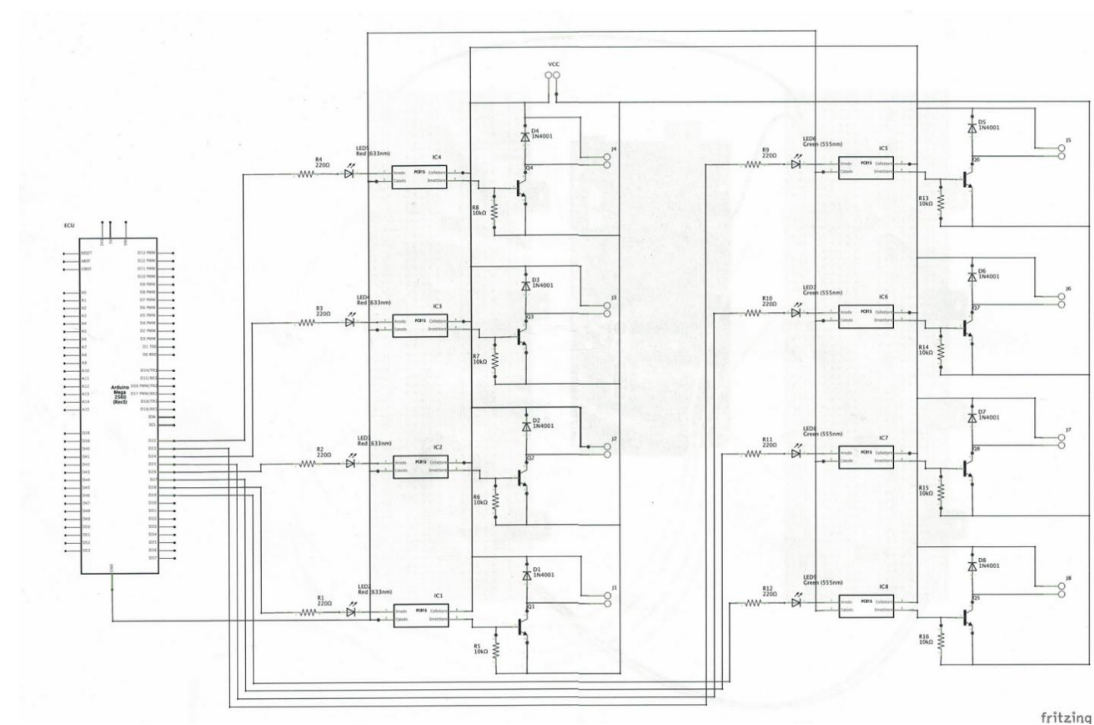

Figure A1- 3 The circuit of the first simulation circuit

In the figure A1-4, the potentiometer is simulated as the throttle of the engine, the servo motor SG90 is simulated as the reciprocating motion of the rod in the cylinder. The temperature sensor which is taken from the engine used for the temperature sensor simulation.
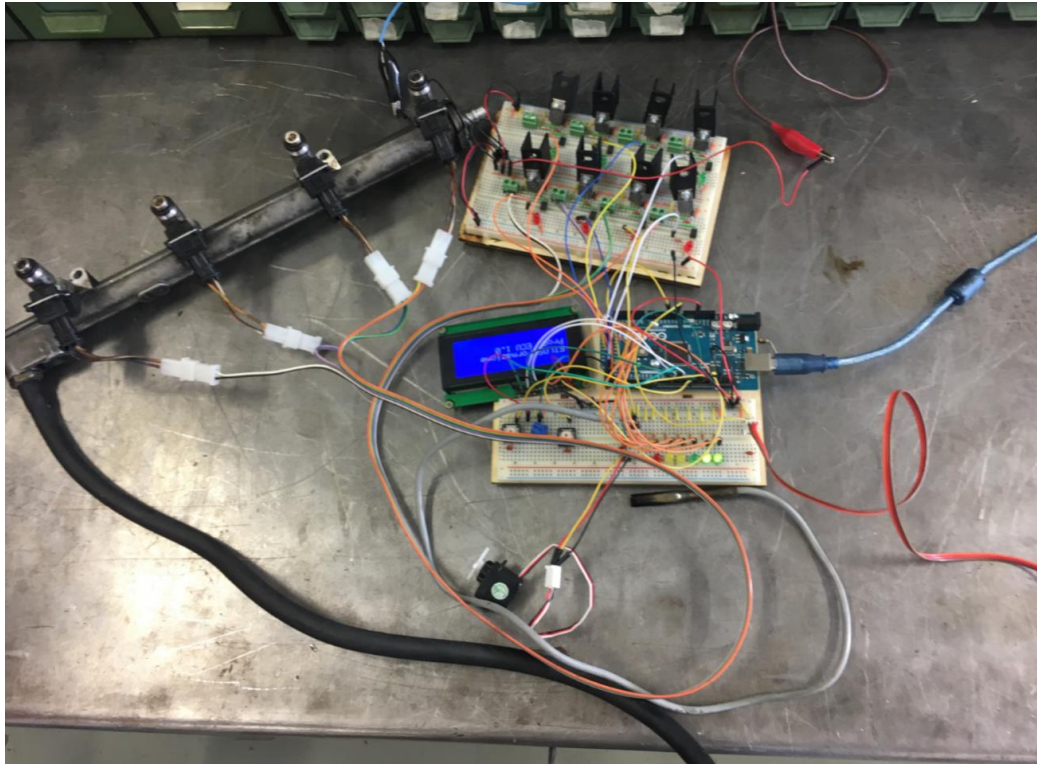
Figure A1- 4 The experimental circuit of the first simulation

A1.2.2The second simulation circuit

The second circuit simulation is mainly to introduce the running of the engine and the RPM sensor.
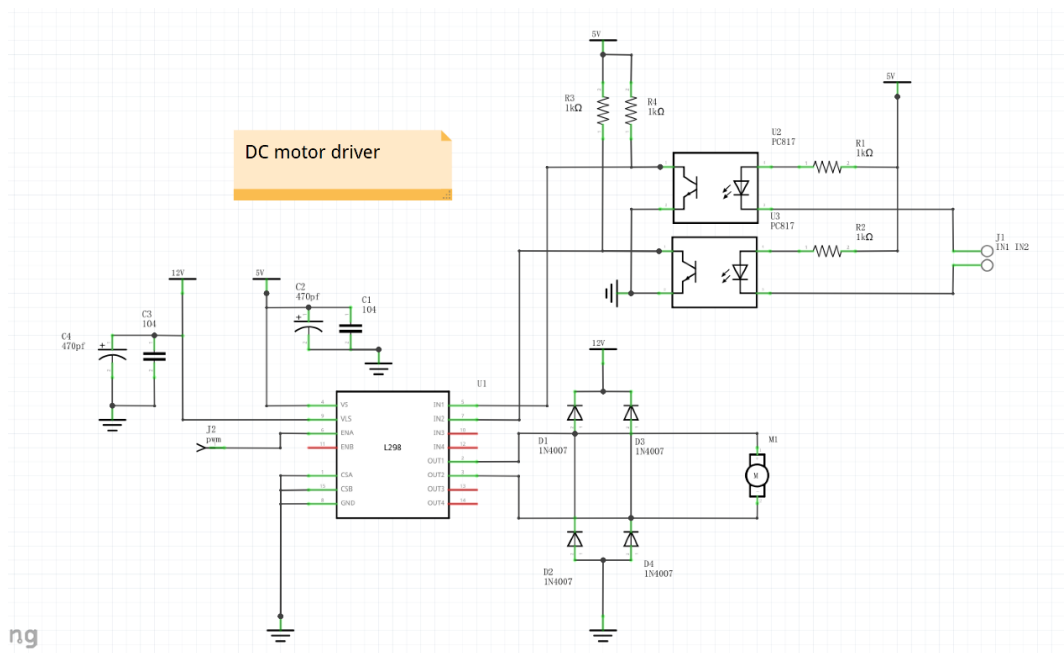

Figure A1- 5 The DC motor diver circuit diagram

The figure A1-5 shows the DC motor driver circuit diagram, and the figure A1-6 shows the optocoupler circuit which simulates as the RPM sensor.
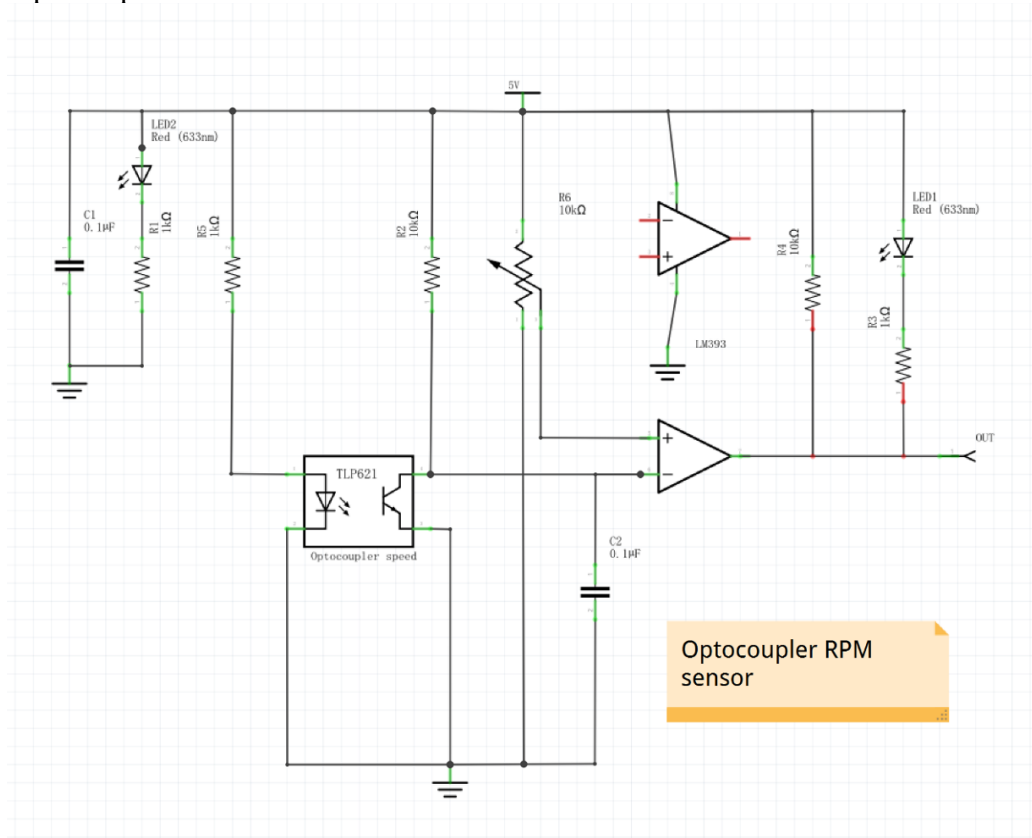

Figure A1- 6 The optocoupler circuit diagram simulates as the RPM sensor

The figure A1-7 shows the experimental circuit including the DC motor which simulates as the engine and the wheel connected to the DC motor simulates as the crankshaft reluctor wheel and the RPM sensor.
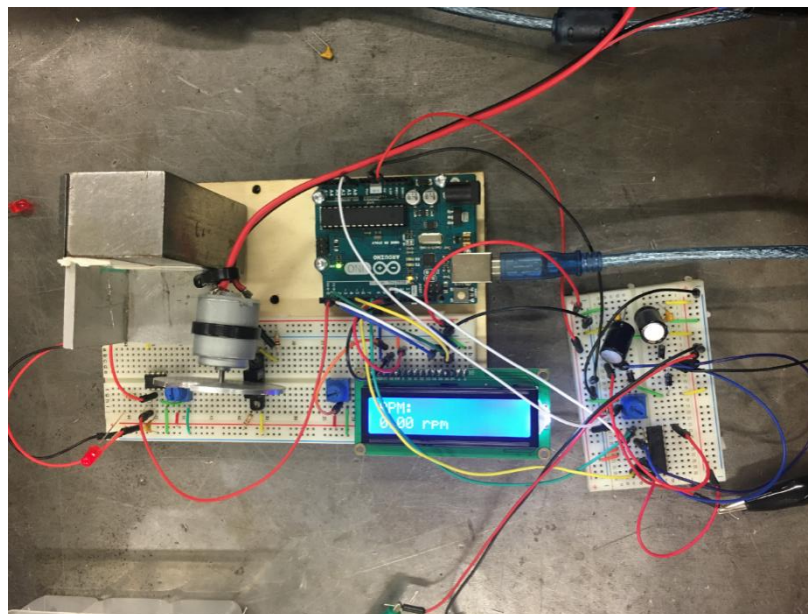

Figure A1- 7 The simulation of the engine and the RPM sensor

A2 Code of the simulation of the engine:

A2.1 The actuators and sensors simulation

The following code shows the code that runs the first simulation circuit. The core code is more likely the ECU of the engine. It is divided in four maps which control the fuel injector stays open and the ignition timing. A part of the code is showing as follow:

```
1.    //assegno il pin 9 al servomotore
2.    servo.attach(9);
3.
4.    LCDSetup ();
5.
6.    }
7.
8.    void loop () {
9.
10.   //leggo lo stato del pulsante
11.   Stato1 = digitalRead (pu);
12.
13.   //creo le funzioni di accensione e spegnimento del motore
14.   if ((Stato1 == HIGH) && (Stato2 == LOW)) {
15.     StatoD = 1 - StatoD;
16.
17.   }
18.
19.   Stato2 = Stato1;
20.
21.   //determino le funzioni quando il motore in stato di on
22.   if (StatoD == 1) {
23.
24.     //leggo il pulsante di selezione mappatura
25.     stato1 = digitalRead (pu1);
26.
27.     //determmino la mappatura
28.     if ((stato1 == HIGH) && (stato2 == LOW)) {
29.       statoD = 1 - statoD;
30.       Serial.print (statoD);
31.       Serial.println ();
32.     }
33.
34.     stato2 = stato1;
35.
36.     //determino le funzioni quando il motore in stato di on
37.     if (statoD == 1) {
38.
39.       //leggo il valore del potenziometro dell'acceleratoree lo adatto
40.       LetturaN = analogRead(p01);
41.       Lettura = map (LetturaN, 540, 900, 0, 1024);
42.
43.       //leggo il valore del sensore di temperatura
44.       Lettura2 = analogRead(st);
45.
46.       //determino i valori dei tempi e della temperatura
47.       temp = (Lettura2/1024.00)*5.00;
48.       temperatura = temp*50;
49.       Val = (T/1024)*Lettura;
50.       rpm = 60000/(Val*2);
51.       Map01 = 7.00 + (-0.000001*Lettura)*(-0.026*(Lettura*Lettura));
52.       Map02 = (((-7.00) + ((64.00/1024.00)*Lettura)) + (-
         0.00008*Lettura)*(0.00025*(Lettura*Lettura)));
53.       Val = Map02;
```

```
54.      t1 = (Val/2)-ti;
55.      t2 = (Val/2)-ta;
56.      tmax = (Val)-(t2+ta);
57.      AA = ((8*rpm)/1000);
58.      AI = ((21*rpm)/1000);
59.
60.      //scrivo sul monitor seriale i dati di controllo
61.      Serial.print (p01);
62.      Serial.print (" ");
63.      Serial.print (LetturaN);
64.      Serial.print (" ");
65.      Serial.println (Lettura);
66.
67.      //Impsto la protezione termica
68.      if (temperatura < ht) {
69.
70.        //imposto il limitatore di rpm
71.        if (Val < 4.47) {
72.
73.          //scrivo sul display l'errore
74.          lcd.clear();
75.          lcd.setCursor (0,1);
76.          lcd.print ("  FILOS ECU 2.0");
77.          lcd.setCursor (0,2);
78.          lcd.print ("Err: Rpm Elevato");
79.
80.          //blocco l'apertura del corpo farfallato
81.          acc = map (Lettura, 0, 1023, 85, 90);
82.          servo.write(acc);
83.
84.          //Accendo la spia dell'errore rpm
85.          digitalWrite (led1,LOW);
86.          digitalWrite (led2,LOW);
87.          digitalWrite (led3,LOW);
88.          digitalWrite (led4,LOW);
89.          digitalWrite (led5,HIGH);
90.          digitalWrite (led6,LOW);
91.
92.          //0-180
93.          digitalWrite (i01, HIGH);
94.          digitalWrite (i02, LOW);
95.          digitalWrite (i03, LOW);
96.          digitalWrite (i04, LOW);
97.          digitalWrite (s01, LOW);
98.          digitalWrite (s02, LOW);
99.          digitalWrite (s03, HIGH);
100.         digitalWrite (s04, LOW);
101.         delay (7);
102.         digitalWrite (i01, LOW);
103.         digitalWrite (i02, LOW);
104.         digitalWrite (i03, HIGH);
105.         digitalWrite (i04, LOW);
106.         digitalWrite (s01, LOW);
107.         digitalWrite (s02, LOW);
108.         digitalWrite (s03, LOW);
109.         digitalWrite (s04, HIGH);
110.         delay (7);
111.         digitalWrite (i01, LOW);
112.         digitalWrite (i02, LOW);
113.         digitalWrite (i03, LOW);
114.         digitalWrite (i04, HIGH);
115.         digitalWrite (s01, LOW);
116.         digitalWrite (s02, HIGH);
117.         digitalWrite (s03, LOW);
118.         digitalWrite (s04, LOW);
119.         delay (7);
```

```
120.        digitalWrite (i01, LOW);
121.        digitalWrite (i02, HIGH);
122.        digitalWrite (i03, LOW);
123.        digitalWrite (i04, LOW);
124.        digitalWrite (s01, HIGH);
125.        digitalWrite (s02, LOW);
126.        digitalWrite (s03, LOW);
127.        digitalWrite (s04, LOW);
128.        delay (7);
129.       }
130.
```

The following code shows the information printed :

```
1.    //leggo il valore del potenziometro dell'acceleratoree lo adatto
2.        LetturaN = analogRead(p01);
3.        Lettura = map (LetturaN, 540, 900, 0, 1024);
4.
5.        //leggo il valore del sensore di temperatura
6.        Lettura2 = analogRead(st);
7.
8.        //determino i valori dei tempi e della temperatura
9.        temp = (Lettura2/1024.00)*5.00;
10.       temperatura = temp*50;
11.       Val = (T/1024)*Lettura;
12.       rpm = 60000/(Val*2);
13.       Map01 = 7.00 + (-0.000001*Lettura)*(-0.026*(Lettura*Lettura));
14.       Map02 = (((-7.00) + ((64.00/1024.00)*Lettura)) + (-
      0.00008*Lettura)*(0.00025*(Lettura*Lettura)));
15.       Val = Map01;
16.       t1 = (Val/2)-ti;
17.       t2 = (Val/2)-ta;
18.       tmax = (Val)-(t2+ta);
19.       AA = ((8*rpm)/1000);
20.       AI = ((21*rpm)/1000);
21.
22.       Serial.print (p01);
23.       Serial.print (" ");
24.       Serial.print (LetturaN);
25.       Serial.print (" ");
26.       Serial.println (Lettura);
27.       if (temperatura < ht) {
28.
29.       //imposto il limitatore di rpm
30.       if (Val < 4.47) {
31.
32.        //scrivo sul display l'errore
33.        lcd.clear();
34.        lcd.setCursor (0,1);
35.        lcd.print ("  FILOS ECU 2.0");
36.        lcd.setCursor (0,2);
37.        lcd.print ("Err: Rpm Elevato");
38.
39.        //blocco l'apertura del corpo farfallato
40.        acc = map (Lettura, 0, 1023, 85, 90);
41.        servo.write(acc);
```

A2.1 The actuators and sensors simulation code

The following part shows the code of the DC motor controlled by the potentiometer.

```
1.    void setup()
2.    {
```

```
3.  //  Serial.begin(9600);
4.  //  pinMode(pu, INPUT_PULLUP);
5.    pinMode(pwm, OUTPUT);
6.    pinMode(pin1, OUTPUT);
7.    pinMode(pin2, OUTPUT);
8.  //  pinMode(pu,INPUT);
9.
10. //  TCCR2B &= ~0x07; TCCR1B &= ~0x07;   //setup pwm register to reduction noise
11. //  TCCR2B |= 1; TCCR1B |= 1;
12. }
13.
14. void loop()
15. {
16. //  int sensorValue = analogRead(A0); //read the value of potentiometer
17. //    val = map(sensorValue, 0, 1023, 0, 255); //change the value range to 0 - 255
18.   analogWrite(pwm, 120); //use the value as a pwm duty cycle
19.
20.
21.     5digitalWrite(pin1, HIGH); //make motor rotate clockwise
22.     digitalWrite(pin2, LOW);
23.
24. //    digitalWrite(pin1, LOW); //make motor rotate anticlockwise
25. //    digitalWrite(pin2, HIGH);
26.
27. //  Serial.println(pu);
28.   delay(500);
29. }
```

The next code shows the code of the RPM sensor which can measure the RPM of the DC motor.
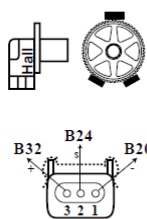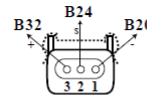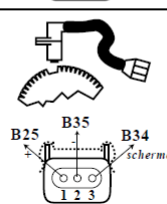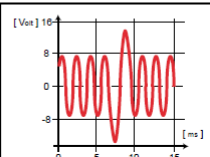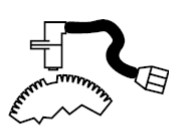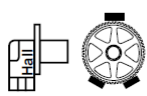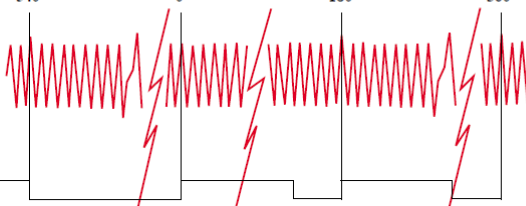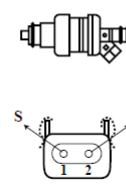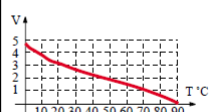
```
1.  //int val = 0;
2.  int pwm = 9; //pwm EA
3.  int pin1 = 8; //I2
4.  int pin2 = 11; //I1  I1,I2 to control the motor direction Clockwise or Anticlockwise
5.  //int pu=3;
6.  //boolean buttonState = false;
7.
8.
9.  void setup()
10. {
11. //  Serial.begin(9600);
12. //  pinMode(pu, INPUT_PULLUP);
13.   pinMode(pwm, OUTPUT);
14.   pinMode(pin1, OUTPUT);
15.   pinMode(pin2, OUTPUT);
16. //  pinMode(pu,INPUT);
17.
18. //  TCCR2B &= ~0x07; TCCR1B &= ~0x07;   //setup pwm register to reduction noise
19. //  TCCR2B |= 1; TCCR1B |= 1;
20. }
21.
22. void loop()
23. {
24. //  int sensorValue = analogRead(A0); //read the value of potentiometer
25. //    val = map(sensorValue, 0, 1023, 0, 255); //change the value range to 0 - 255
26.   analogWrite(pwm, 120); //use the value as a pwm duty cycle
27.
28.
29.     5digitalWrite(pin1, HIGH); //make motor rotate clockwise
30.     digitalWrite(pin2, LOW);
31.
32. //    digitalWrite(pin1, LOW); //make motor rotate anticlockwise
33. //    digitalWrite(pin2, HIGH);
34.
```
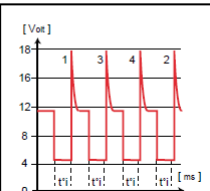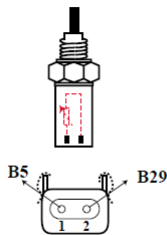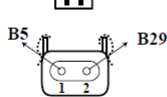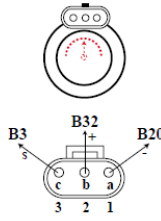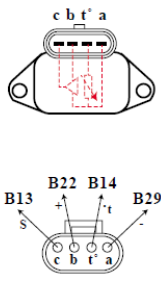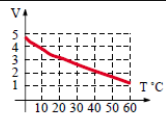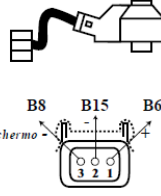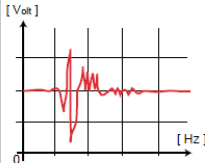
```
35.  // Serial.println(pu);
36.    delay(500);
37.  }
```
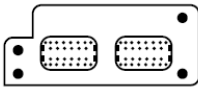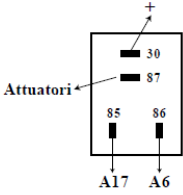
Appendix B:

The reference value of the sensors and actuators of the engine.

OPERAZIONI DA ESEGUIRE SUL SISTEMA IN ESAME					Pag **2**	RIF **LA 017**

COMPONENTI e pin centralina	CHIAVE	TERM. CONNETT. CENTRALINA	TERM. CONNETT. COMPONEN.	OPERAZIONI DI CONTROLLO (le spine sono viste lato collegamento attuatori)	VALORI e/o OSCILLOGRAMMA DA RILEVARE

Sensore di fase

	Mar	+ B 32	– B 20	+3	–1	Tensione alimentazione	4.8 ÷ 5 Volt
(B32 B24 B20 — 3 2 1)	Moto	s B 24	– B 20	–1	s 2	Segnale (3 rilievi su puleggia= 1 largo e 2 medi) (motore al minimo 2.5 Volt)	[Volt] / 0 / [Hz]

Sensore di giri / P.M.S.

	Moto	+ B 25	– B 34	+1	–2	Segnale (ruota fonica 60 - 2)	[Volt] 16 / 8 / 0 / -8 / [ms] 0 5 10 15

Sincronizzazione segnali in centralina

PMS cilindri	2	1	3	4
Angoli abero motore	540°	0°	180°	360°

Segnale ruota fonica

Sensore di fase

Elettroiniettori

	Moto	B28			Cil 1	Segnale comando (In fase di avviamento vengono comandati contemporaneamente per 5 sec. "full-group") (Limitazione giri oltre 6800 per 10s)	[Volt] 18 16 12 8 4 0 [ms]
		B36		1	Cil 2		1 3 4 2
		B37		2	Cil 3		
		B27			Cil 4		

Sensore temperatura motore

	Moto	B5	B29			Tensione alimentazione (spina scollegata)	4,5 ÷ 5 Volt
(B5 B29 — 1 2)	Moto	B5	B29			Segnale di riferimento (5 V in diminuzione con l'aumento della temperatura)	V 5 4 3 2 1 T°C 10 20 30 40 50 60 70 80 90

Stop = Commutatore non inserito;   Mar = Commutatore inserito

OPERAZIONI DA ESEGUIRE SUL SISTEMA IN ESAME					Pag **1**	RIF **LA 017**

CENTRALINA	CHIAVE	TERM. CONNETT. CENTRALINA		OPERAZIONI DI CONTROLLO	VALORI e/o OSCILLOGRAMMA DA RILEVARE

(N.B. CHIAVE DISINSERITA RICOLLEGARE CENTRALINA)

	CHIAVE	TERM. CONNETT. CENTRALINA		OPERAZIONI DI CONTROLLO	VALORI e/o
	Stop	⏚		(tra gruppo centralina e motore) **Controllo circuito masse** (tra gruppo centralina e carrozzeria)	**Max 1 Ω**
	Mar	⏚	A4	*permanente* **Tensione** alimentazione: *a chiave inserita*	**10 ÷ 15 Volt**
			A 17		

COMPONENTI e pin centralina	CHIAVE	TERM. CONNETT. CENTRALINA	TERM. CONNETT. COMPONEN.	OPERAZIONI DI CONTROLLO (le spine sono viste lato collegamento attuatori)	VALORI e/o OSCILLOGRAMMA DA RILEVARE

Relè principale (portarelè e relè rosso)

	CHIAVE				
	Stop		⏚	30	**Tensione** permanente	**10 ÷ 15 Volt**
	Mar		⏚	85	**Tensione** a chiave inserita	**10 ÷ 15 Volt**
			86	85	**Comando** relè (collegato)	(per 5 sec) **10 ÷ 15 Volt**
			⏚	87	**Per chiusura** relè (collegato)	(per 5 sec) **10 ÷ 15 Volt**

Potenziometro acceleratore

	Mar	- B 20	+ B 32	- a	+ b	**Alimentazione**	**4,8 ÷ 5 Volt**
	Moto	- B 20	s B 3	- a	s c	**Segnale d'uscita** (a riposo)	**0,8 Volt**
						(a fondo corsa)	**4,8 Volt**

Sensore pressione assoluta / temperatura aria

	Mar	- B 29	+ B 22	- a	+ b	**Alimentazione**	**4,8 ÷ 5 Volt**
	Moto	- B 29	s B 13	- a	s c	**Uscita** segnale sensore pressione assoluta	Chiave inserita **4,2 ÷ 4,5 Volt**
							al minimo **1,2 ÷ 1,5 Volt**
							Pieno carico **4,2 ÷ 4,5 Volt**
			B 14	- a	°t	**Segnale** sensore temperatura aria (in diminuzione con l'aumento della temperatura)	*grafico V / T °C*

Sensore di battito

	Moto	- B 15	+ B 6	1	2	**Segnale** comando (Per riduzione anticipo)	*oscillogramma [Volt] / [Hz]*

Stop = Commutatore non inserito;   Mar = Commutatore inserito

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MISURA	CHIAVE	DATI TECNICI		VALORI DA RILEVARE
		Misure di resistenza su Attuatori		
Ohm	Stop	**Singolo elettroiniettore**		**14 ÷ 16 Ω**
Ohm	Stop	**Sensore di giri / P.M.S.** *(term 1 - 2)*		**1100 ÷ 1400 Ω**
Ohm	Stop	**Riscaldamento sonda Lambda** *(term 3 - 4)*		**3 Ω**
Ohm	Stop	**Elettrovalvola vapori benzina**		**35 ÷ 58 Ω**
Ohm	Stop	**Sensore di battito**		**530 ÷ 580 Ω**
Ohm	Stop	**Attuatore del minimo**	*(term A - D)* *(term B - C)*	**50 ÷ 60 Ω**
Ohm	Stop	**Potenziometro acceleratore** *(term a - b)*		**1200 ÷ 1250 Ω**
		(term a - c)		**0 → 1200 Ω**
Ohm	Stop	*(motore)* **Sensori temperatura** *(aria) (nel sensore pressione assoluta)*	*0 ˚C* *10 ˚C* *20 ˚C* *60 ˚C* *80 ˚C* *90 ˚C*	**9.5 KΩ** **3.8 KΩ** **2.5 KΩ** **500 Ω** **300 Ω** **200 Ω**
Ohm	Stop	**Bobina A.T.**	*(primario)*	**0,5 ÷ 0,65 Ω**
			(secondario)	**6850 ÷ 7850 Ω**

N.B.

Le misure di resistenza sono misurate a circa 20˚ C direttamente sugli attuatori.

(collegamenti scollegati)

Stop = Commutatore non inserito;   Mar = Commutatore inserito

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